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GUIDELINES FOR PROGRAM DEVELOPMENT(U) SHIP STRUCTURE
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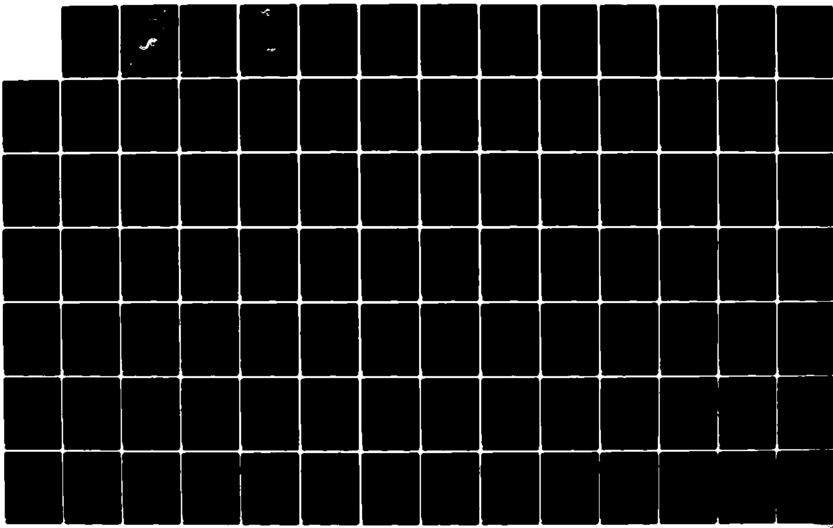

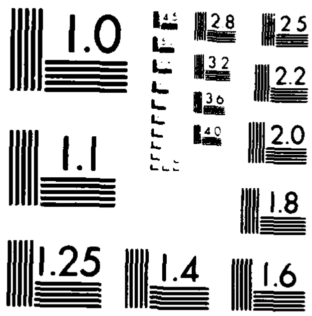
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SHIP STRUCTURE COMMITTEE LONG-RANGE RESEARCH PLAN

GUIDELINES FOR PROGRAM DEVELOPMENT

SHIP STRUCTURE COMMITTEE

1983

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Ship Structure Committee

An Interagency Advisory Committee
Dedicated to Improving the Structure of Ships

Address Correspondence to:

Secretary, Ship Structure Committee
U.S. Coast Guard Headquarters, (G-M/TP 13)
Washington, D.C. 20593

13 JAN 1984
SR-1296

The Ship Structure Committee is an "Interagency" committee composed of senior officials, one each from the U.S. Coast Guard, the Naval Sea Systems Command, the Military Sealift Command, the Maritime Administration, the American Bureau of Shipping, and the Minerals Management Service. The mandate of the Ship Structure Committee is "to conduct an aggressive research program which will, in light of changing technology in marine structures, improve the design, materials and construction of the hull structure of ships and other marine structures by an extension of knowledge in these fields, for the ultimate purpose of increasing the safe and economic operation of all marine structures."

The Ship Structure Committee is assisted in the conduct of its research and development activities by the Committee on Marine Structures of the National Academy of Sciences. The role of the Committee on Marine Structures is "....to provide technical assistance for development and completion of the continuing research programs of the Ship Structure Committee."

This report documents a proposed long range research program plan for the Ship Structure Committee. Hundreds of industry representatives have aided in its formulation and to each we express our appreciation.

Cly[illegible] T. [illegible].
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

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16. Abstract

This study constitutes a look at the long-range needs and opportunities to improve ship structure through research and development initiated between now and A.D. 2000. Eight different types of trends were reviewed along with their implications for the maritime industry: Technological innovations, resource availability, trends in ship/platform types and populations, political, legal, economic, military, and environmental. Eighty-five work parcels (a mutually supporting set of R & D taks which are essential components for achieving a specific goal) have been ranked in four groups-- Top, Second, Third and Fourth--on the basis of their judged importance.

The report has seven conclusions, among them being: ...that the nation will benefit most from structural improvements to the Navy/national defense, oil and gas, and transportation systems. Secondly, analyses revealed that the national value of structural improvement will be greatest for improvements to medium-sized monohulls, semisubmersibles, large monohulls and bottom-mounted platforms, in that order.

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METRIC CONVERSION FACTORS

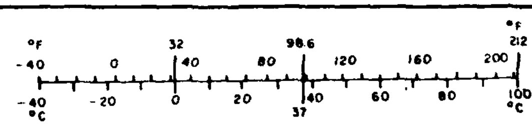
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

We want to thank the ad-hoc Project SR-1296 Advisory Committee which helped to guide us among the myriad of options for conducting the study. This committee consisted of:

Ship Structure Subcommittee

Mr. A. B. Stavovy, Chairman
Capt. R. L. Brown, USCG Liaison
Mr. J. B. O'Brien, NavSea Liaison
Dr. Don Liu, ABS Liaison
Mr. T. W. Chapman, MSC Liaison
Mr. R. J. Giangerelli, USCG Liaison
Mr. F. Seibold, MarAd Liaison

Committee on Marine Structures

Mr. A. D. Haff, Chairman
Mr. J. E. Steele, Member
Mr. D. A. Sarno, Member

Especial thanks goes to Lt. Cdr. D. B. Anderson, USCG, Secretary of the Ship Structure Committee, and to Mr. R. W. Rumke, Executive Secretary of the Committee on Marine Structure for their cooperation in scheduling meetings and providing materials.

The building blocks of this project were obtained from the in-depth earlier study, Project SR-1259 Ship Structure Committee Long Range Research Plan (LRRP). We are indebted to the many scientists and engineers who contributed their time and expertise. We are indebted especially to Mr. J. J. Hopkinson, Dr. J. G. Giannotti, Mr. Forrest Kinney and Miss Majorie Murtagh who interpreted the earlier work and helped us to assemble the records.

Investigators for SR-1296:

Edward M. MacCutcheon   Owen H. Oakley   Robert D. Stout

CONTENTS

INTRODUCTION

Effective utilization of the oceans by the United States hinges on the availability of the best systems to do the job. For one thing this means that they must have efficient structures and that is the subject of the study reported here. The oceans, Great Lakes and rivers of the United States serve the nation in many ways. We benefit from their commercial use by shipborne commerce and from the recovery of seafood, minerals, chemicals and drugs. The oceans support our national defense and security by affording a maneuvering area for our navy and hiding place for our submarines. They increasingly provide us with a source for oil and gas and in the future we hope they will be a source of renewable solar energy. Finally, but not to be ignored, the oceans and waterways provide recreation, including the operation of some fourteen and a half million pleasure craft in the United States. (In this report the term "ocean" is considered to include the Great Lakes and inland waterways as well as coastal waters and deep ocean.)

Securing national benefits from the oceans involves hundreds of ships and offshore platforms, thousands of small working craft and millions of pleasure craft. Utilization of more efficient and reliable structure in the hulls, framing and appendages of these ships and platforms can represent a substantial national economic benefit and provide improved safety. The purpose of the Ship Structure Committee program in structural research and development is to contribute to continuing improvement in United States ships, platforms and craft of all types through improvements in design, materials and fabrication methods.

This study constitutes a look at the long-range needs and opportunities to improve ship structure through research and development initiated between now and A.D. 2000. The aim of the study is to provide the Ship Structure Committee (SSC) and its associated planning groups and staff with guidance that will be useful in formulating five-year and annual plans for research and development programs and projects.

The work is based largely on an unpublished study which is described in Appendix A and identified herein as the LRRP study. Because that study is unpublished, an effort has been made to make this report self-contained.

The investigators on this study recognized the need for a pattern to pull together the global trends, system needs, technological opportunities and the technical shortfalls which had to merge in defining the desirable research and development for the SSC. The flow of needs and opportunities leading to the recommended research and development guidelines is outlined in Figure 1, which served as the "road map" for the study.

The expression of need starts in the upper left with the selection of the most likely scenarios, trends and projections governing U.S. ocean activities. Moving to the right the trends and projections determine the likely ocean activities and resulting benefits in the target future year, A.D. 2000. Moving

downward the projections determine the abundance of energy and minerals that control the types of materials and associated fabrication systems needed.

The expected activities in the oceans determine the needed ocean systems that in turn govern the potentially promising ship and platform configurations and finally the needs for new technology.

Novel technological opportunities introduce important perturbations among the options for needed technology, be they configurations, materials or fabrication techniques.

Finally the technological needs, the novel opportunities, and the other options for improvement are melded in an expression of desirable research and development. These are the guidelines for planning Ship Structure Committee R & D programs and they are the product of this study. They are the tools the SSC needs to formulate its long-range programs and its five-year and annual plans. (See the lower right of Figure 1.)

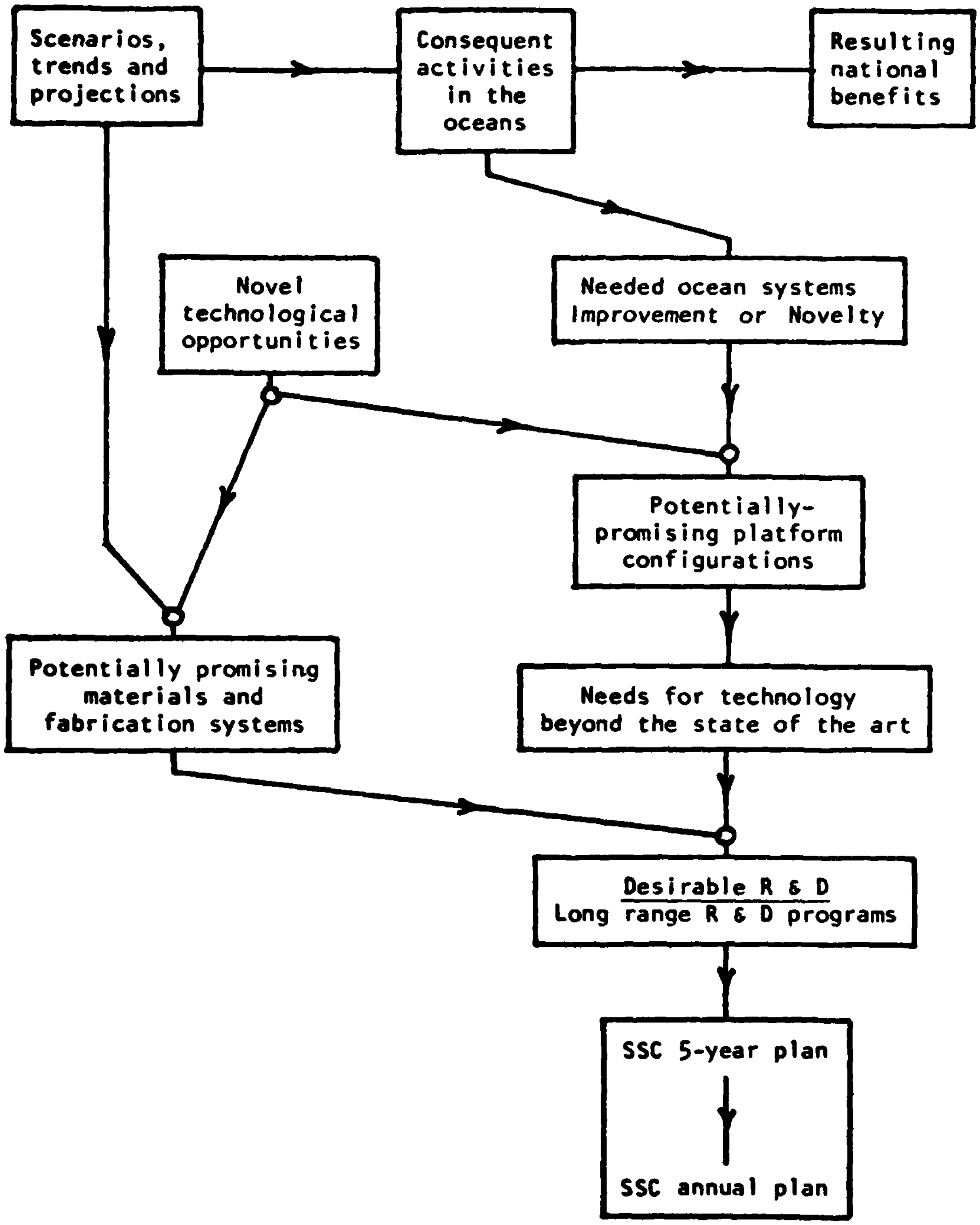


Figure 1 Logic Flow for Plan Formulation

UNITED STATES OCEAN ACTIVITIES

Forecasting

Forecasts for 10 to 20 years are very risky because the course of prevailing trends is so easily perturbed by political whim or by economic, social or technological surprise. Nevertheless, we know that the utilization of the oceans in A.D. 2000 will be different from what it is today. Thus, a reasonable projection is better than assuming extension of the status quo.

There is a long lead time in the use of new knowledge. Scientific research maturation may take 16 years from theory to professional practice. Probably 6 - 8 years of this is a reasonable gestation period for development. To these periods must be added the ship construction period from preliminary design to commissioning: for merchant ships 3 - 5 years, and for naval ships 5 - 8 years. Thus, for this study, near term is 1980 - 1990 and long term is 1990 - 2000. Actually some novel concepts now under development will not be in use until after A.D. 2000.

The LRRP study identified four scenarios for the forecasts:

A - High interdependence, based on highest possible levels of cooperation among all nations, resulting in maximum world economic growth.

B - Moderate interdependence, based on more likely levels of cooperation, growth inhibited over scenario A by changes in societal values and/or socioeconomic structural difficulties.

C - Break between the developed and developing countries.

D - Break among developed nations, characterized by protectionism discouraging worldwide trade and encouraging regional trade (e.g. North and South America, rather than U.S. and Japan).

We chose to use conservative scenario B.

Eight different types of trends were reviewed along with their implications for the maritime industry:

- Technological innovations
- Resource availability
- Trends in ship/platform types and populations
- Political trends
- Legal trends
- Economic trends
- Military trends
- Environmental trends

Many trends were found to impact activities in the ocean but the following seven trends pervade ocean activities more completely than do most other trends:

1. Rising costs of energy in reaction to the specter of depletion of petroleum reserves:

   The increases in all energy costs, consequent to the petroleum shortages, are impacting the ocean industries in many ways. Ship fuel costs increased immediately. Offshore petroleum exploration is increasing. Coal shipments have increased dramatically and a variety of ocean energy sources are being developed.

   Shipbuilding and offshore platform materials are also soaring because of their high energy content. Steel costs are rising; aluminum costs are rising faster and titanium even faster. Fiberglass cost is rising and in addition the resin is a petrochemical.

2. An increasing scarcity of many key minerals in the U.S.:

   Manganese, at prevailing prices, is 100% imported. Other alloying elements are also in short supply. Ocean activities are involved through the push for offshore mining. Ocean mining has started with the most mundane and most exotic of minerals, sand and gravel and diamonds.

   Heavy metal dredging has been sporadic in river deltas and mining of manganese nodules awaits law of the sea treaties with foreign nations. New discoveries of rich polymetallic sulphide deposits in the oceans remain to be assessed.

3. Increasing intensity in competition for ships to build:

   The existing shipbuilding capacity worldwide is more than twice what is required for current orders. Emerging nations with low cost labor are competing, while Federal subsidies to U.S. shipbuilders are waning.

   In the last decade the U.S. has received orders for high technology ship types, but more recently Japan and European nations have been capturing that market from us.

4. Degeneration of U.S. commercial shipping:

   The slow, steady six-tenths percent yearly increase in world trade is offset in part by decreases in tanker cargoes and by the increasing proportion of short-haul transport as emerging nations enter international commerce.

   The U.S. is the greatest trading nation in the world but its fleet carries only five percent of its overseas shipments and

the situation continues to deteriorate as subsidies are further curtailed. The U.S. is hauling a tiny and shrinking fraction of a relatively level world maritime traffic.

5. A gradually increasing naval force:

The prevailing effort to increase warship construction can be expected to continue for three reasons: a) US/USSR military competition is not expected to lessen, b) increased offshore exploitive activities will require increased U.S. naval presence, and c) substantial arms sales to the third world will probably continue for the foreseeable future.

6. Increasing operations in cold waters:

Oil and gas recovery is increasing in arctic cold water areas. The consequent increase of ships and platforms exposed to frigid environments will result in an increased risk of structural failure due to steel frac ure and problems from ice loading.

7. Vessels will be larger:

In every merchant ship type, increasingly larger vessels will be built. The size of the average ship of the U.S. foreign trade fleet is projected to increase about one-quarter in deadweight tonnage. However the largest new ships are unlikely to approach the ultra-large tankers (ULT) which have been built in the past.

Ocean systems in A.D. 2000

In consequence of the foregoing trends we anticipate that sixteen types of ocean systems involving essential primary oceangoing structures will be active in A.D. 2000. It is reasonable to forecast qualitatively the growth trends for each type of system. The systems types and growth trends are displayed in Table 1.

TABLE 1

TYPES OF OCEAN* SYSTEMS INVOLVING
ESSENTIAL PRIMARY OCEANGOING STRUCTURES

Types of System	Growth Trend
Transportation systems	Slightly increasing
Navy/national defense	Increasing
Fishing systems	Increasing
Aquaculture/mariculture systems	Increasing
Harvesting systems for chemicals and drugs	Increasing
Ocean power generation systems	Strongly increasing
Ocean-sited industrial plants or terminals	No significant change
Oil and gas recovery systems	Very strongly increasing
Deep-sea mining systems	Strongly increasing
Waste disposal systems	No significant change
Recreation systems	Increasing
Dredging systems	Increasing
Mapping and charting systems	No significant change
Navigational aids systems	No significant change
Salvaging systems	Increasing
Securing, policing and patrolling systems	Increasing

* N.B. The term "ocean," as used in this study, encompasses the Great Lakes and the navigable rivers.

VALUE OF STRUCTURAL IMPROVEMENT

The key question is: What can the SSC programs do for the United States by structurally improving the 16 ocean systems by A.D. 2000? This question conjures up three subordinate questions: 1) How important will each ocean system be to the United States? 2) What impact will structural improvement have on productivity, efficiency and safety of each ocean system? and 3) How much structural improvement is achievable through the SSC research and development by A.D. 2000? Answers to these questions are essential to determining the best emphasis among efforts to improve ocean system structures through research and development.

The value of structural improvement is the measure of merit of the structural R & D efforts; this analysis to determine the most desirable emphasis among the multitude of R & D options. It startw with the relative potential value to the United States of achievable structural improvement of ocean systems stemming from the SSC research and development. As implied by the questions in the proceeding paragraph the value of structural improvement may be considered to have three components. This is illustrated conceptually in the following:

- Relative importance to the United States. (U.S.)
- Relative system improvement due to structural improvement (R)
- Achievable structural improvement (e)

Then, for each ocean system, the value of structural improvement would be:

$$v_n = (U.S.)_n \times (R)_n \times (e)_n \text{, for the } n^{th} \text{ ocean system.}$$

Relative importance to the United States

The best judgement regarding the relative importance of a national system should reflect the attitude of the people and the government. This can be expressed by the relative role the system plays in the national economy. Data on the Gross National Product, gross sales and Federal appropriations were melded to obtain a rough figure reflecting the relative importance of the 16 ocean systems.

Two tests for significance were made for each apparently important system. These were: evaluation of future construction activity and evaluation of future operational activity. Shipbuilding production tonnage and the numbers of ships and platforms in operation, estimated for A.D. 2000, were used as measures of significance.

All of the economic and ocean systems data were estimated as of the year A.D. 2000. Most of this information came directly from reference sources and very little from the intuitive judgements of the investigators. The three principal sources for the projections were:

1) Merchant Fleet Forecast of Vessels in U.S. - Foreign Trade, Temple, Barker & Sloane, Inc., for the U.S. Department of Commerce, Maritime Administration, May 1978.

2) A Technology Assessment of Offshore Industry and Its Impact on the Maritime Industry 1976 - 2000, The BDM Corporation for the U.S. Department of Commerce, Maritime Administration, August 1977.

3) Estimates for the U.S. Navy provided informally by U.S. Navy liaisons to the Ship Structure Subcommittee.

Brief descriptions circa A.D. 2000 of the seven major ocean systems important to this study are contained in Appendix B.

Relative System Improvement Due to Structural Improvement

Combat systems of the navy benefit directly from weight savings. Every pound saved can be converted to a pound of combat effectiveness. Weight savings mean fuel and consequent economy for transportation systems, or alternatively increased productivity, or safety if the ships are not weight limited. Weight is crucial to the high-performance craft such as the hydrofoil or SES. For other types of craft or platforms weight may be less crucial and the benefits of structural improvement may be realized in other ways.

These factors were considered by the investigators and each ocean system was judged relative to the others in terms of the probable impact of the improvement of oceangoing structure on the overall improvement of the system.

Achievable Structural Improvement

This factor expresses the benefit to be expected from SSC research and development to A.D. 2000. The principal element is the technical shortfall between the state of the art now and what might prevail in A.D. 2000. Considerations such as the intensity of R & D applied in the past, opportunities for improvement, and the tractability of the technology are pertinent.

Again the investigators made relative judgements among the ocean systems.

Value to the U.S. fr[illegible] Structural Improvement to Each Ocean System

Synthesizi[illegible] [illegible]regoing information and judgements for the 16 ocean systems, the inve[illegible] found it possible to rank them in terms of the potential value [illegible] the U.S. from improvement to each system.

In the process the systems were regrouped and their number reduced from 16 to 11. Our judgement regarding the allocation of value of structural improvement is displayed in Table 2.

TABLE 2

TYPES OF OCEAN SYSTEMS IN A.D. 2000 RANKED BY
THE VALUE OF STRUCTURAL IMPROVEMENT

Greatest value:

Navy/national defense
Oil and gas recovery systems

Second greatest value:

Transportation systems

Substantial value:

Recreation systems
Ocean power generation systems
Fishing/aquaculture/mariculture systems
Ocean-sited industrial plants

Lesser value:

All other systems

While the dominance of the ocean systems associated with the navy and the oil and gas industry was to be expected, the magnitude of value assignable to recreational boating was a surprise.

PROMISING TECHNOLOGY

Determining the desirable research and development for the SSC calls for a recognition of the most critical system needs and technical problems and opportunities to solve problems and improve structure. This section deals with the opportunities.

Novel technological opportunites promise superior solutions to many old problems. They even promise to remove traditional constraints previously too intractable to be labelled problems. The modern computer is an outstanding example of a versatile novel technology.

There are many opportunities for technology transfer from other industries and nations. One example is the possibility of borrowing metallurgical alternatives to normalizing for higher toughness steel from the pipeline industry instead of performing research and development.

Finally, systems needs may be satisfied by improvements rather than novelty. An example is the contest between submarine tankers and high powered ice breaking surface tankers for arctic operations.

Novel technological opportunities

The application of new knowledge or innovation involving novel technology offers some of the best opportunities to improve. The following novel technological opportunities promise to enhance the effectiveness of research and development regarding ocean structures:

Computer-aided design

Novel applied-mathematical solutions (including the finite-element method and time-domain analysis) and optimization through availability of computers.

Computer-aided manufacturing and other electronically controlled robotics

Statistical methods as applied to:

Failure analysis
Reliability and risk
Seaway description

Structural soundness monitoring capabilities

Lifetime cost optimization in design

Maintenance cycle cost optimization in operation

Advanced information exchange

Advanced education and training

New sources of scarce minerals

Advanced environmental prediction

A goodly share of the projects covered by the LRRP study were found to include novel technological opportunities. These opportunities were also a featured consideration in conducting the work parcel evaluations described later in this report. A few work parcels have been added in recognition of these opportunities. The work parcels are considered to include a balanced involvement of novel technologies.

Potentially promising materials and fabrication systems

Long-term planning for research in materials must take into account likely trends in the availability of the various materials for ship construction and the requirements that they will have to meet for improvements in marine structures. The matrix (Table 3) comprises the material parameters that are considered significant to the planning process. It is recognized in this matrix that: (1) the fundamental properties required of materials to meet marine applications relate to combinations of static and fatigue strength, notch toughness and corrosion resistance; (2) important economic factors include material cost, abundance, ease of fabrication into large structures and repairability; and (3) the opportunities for improvement of these material characteristics range from promising to doubtful.

TABLE 3

MATRIX OF MATERIAL CHARACTERISTICS

Characteristics	Steels			Aluminum Alloys		Concrete	Polymers	Titanium
	High-Strength low alloy	Alloys for low temp.*	Austenitic	High toughness	High strength	Reinforced	Fiber Reinforced plastic	
Availability	A	B	C	B	B	A	A	C
Cost	A	C	C	B	B	A	B	C
Strength	A1	A3	A2	C2	A2	C1	A2	A3
Notch Toughness	B1	A1	A3	A3	B3	B2	B2	B3
Weldability	A1	B2	B2	B2	B3	--	--	C2
Formability	A2	B3	B3	A3	B2	--	B2	B3
Corrosion Res.	B2	A2	A2	A3	B3	A2	A3	A3
Strength/Weight	B2	B3	A3	A2	A3	B1	A2	A3
Fire Resistance	A3	--	A2	C2	C3	A2	C2	A3
Repairability	A1	B1	B2	B2	C2	B1	B2	C2

* Refers both to ship operational environment and cryogenic levels.

Notes:

1. Numerals in columns indicate opportunity for improvement: 1 high; 2 moderate; 3 low.
2. Letters in columns indicate present status: A good; B moderate; C poor.
3. Other characteristics that might be added include energy requirement, and scrap recoverability.

NEEDS FOR TECHNOLOGY BEYOND THE STATE OF THE ART

The LRRP study (Appendix A) contained a major review of the prevailing technical situation. The study was conducted by blue-ribbon groups of engineers and scientists, as listed in Appendix A.

In conducting the review these groups established a work-breakdown structure for the whole domain of ship structure. They reviewed the state of the art in all areas and specified the research needs. They defined primary and secondary problem areas, and sought means of tackling the problems. These efforts resulted in a set of 21 programs and 190 projects.

The work of the LRRP was fully utilized in this study. What is more, the technical appraisals are considered so valuable to program planners that we have attempted to capture the key information and to report it here. It was the primary technical foundation on which the present study was based. Our summary of this information is in the form of technical-area situation reviews and is in Appendix C. These reviews are largely based on the LRRP study and liberally paraphrase or quote it.

The principal thrust of the SSC program, this study, is innovation of supporting technology. Basic science has not been considered, nor on the other extreme have the unique problems of specific ship designs. Thus, the selection of both opportunities and problems for SSC program guidance relates to supporting technology.

DESIRABLE RESEARCH AND DEVELOPMENT

In order to formulate our recommendations regarding the long-term programs to be pursued by the Ship Structure Committee, the projects developed by the LRRP Workshops were reviewed and incorporated into "work parcels." These parcels were then evaluated for their relevance and usefulness to the improvement of ship and platform structure. We have defined the term "work parcels" as a a mutually supporting set of R & D tasks which are essential components for achieving a specified goal. The term work parcel was introduced to avoid semantic confusion with the terminology "projects" and "programs" of the LRRP study. The size of the work parcels has been deliberately minimized to ease problems of budgeting.

Many of the projects proposed in the LRRP study are inadequately described for evaluation purposes. The time available to the visiting engineers and scientists at the two workshops was far less than required for group formulation of fully useable descriptions. Although we examined each project in the LRRP and used them to formulate the work parcels, we were not able to critically review and revise all project descriptions. Nor was this intended or feasible in the context of the present effort. However, wherever possible we have provided required additional information regarding the scope and other features of the proposed work.

The work parcels developed from the review of the LRRP projects are presented in Appendix D. Appendix D is in two parts; Part One, a list of work parcels and Part Two, a description of each. These are the 85 work parcels that were subjected to the evaluation process and ranked for recommendation.

Procedure of evaluation

The evaluation of the work parcels is in two parts. First an effort was made to determine how much value would accrue to the U.S. from the completion of the work parcel. Second, factors such as the chance of success and the cost were introduced in order to measure benefits against costs and determine which work parcels are the "best buys" for the SSC. This measure of quality is called "importance."

The most difficult problem made itself known at the very outset, when it was found that we could not encompass the scope of judgements necessary to place national level potential values of improvement against the work parcels. Another, more workable, approach had to be found.

Potentially promising platform configurations

To facilitate the job of evaluating laboratory work parcels in the lofty domain of national value, a transfer device was invoked. Platform configurations were tried as a bridge to tie the national values down to a level where decisions could be made with recognition of the technical content of the work parcels.

Twelve basic configuration types were selected to include all of the plausible possibilities. In this context the term platform includes ships, craft of all sizes, and platforms of all types, both semi-submersible and bottom-mounted. The latter includes jack-up rigs as well as gravity-base or template-jacket platforms.

The twelve types of platforms are:

Large monohull (over 700-ft. long)
Medium monohull (300- to 700-ft. long)
Small monohull (under 300-ft. long)
Multihull, including small waterplane area twin hull (SWATH)
Surface effect ship (SES)/Air cusion vehicle (ACV) and hydrofoil
Planing craft
Semisubmersible
Bottom-mounted platforms
Tension leg platform (TLP)
Submarine
Submersible
Collateral structures*

*Collateral structures include moorings, power cables, offshore technology energy conversion (OTEC) cold water pipes (CWP), outfalls, mineral dredges, etc.

The potential value of structural improvement that had been determined for each ocean system was distributed among all of the configuration types present in the system. This distribution among qualified platform configurations was made on the basis of a judgement as to the probable future use of the configuration and the probability of its improvement.

For each ocean system the total value allocated to the configuration types equalled the value estimated to be potentially available from improvement of the whole system. The final step in this part of the process consisted of summing, for each type of configuration, the shares of the value allocated to it from each ocean system. This process is illustrated conceptually in Figure 2, where it will be noted that the total potential value attributable to the ocean systems is equal to the total value attributable to the configurations.

This configuration/transfer process brought the value of improvement information down to a level where it could be handled in terms of judgements involving the technology of the work parcels. The necessary judgements were found to be manageable for two reasons: they consisted of a form of ranking among a reasonable number of familiar concepts, and there were recognizable boundaries on the operation.

The result of the value allocation among the platform configurations is displayed in Table 4.

U. S. Ocean Systems

Platform Configurations	(1) Navy	(2) Oil and gas	(3) Transportation		(n)		(11) Dredging	Configuration total
(a) Medium monohull	$V_{1,a}$	$V_{2,a}$	$V_{3,a}$	+	$V_{n,a}$	+	$V_{11,a}$	V_a
(b) Semisubmersible	$V_{1,b}$	$V_{2,b}$	$V_{3,b}$	+	$V_{n,b}$	+	$V_{11,b}$	V_b
(c) Large monohull	$V_{1,c}$	$V_{2,c}$	$V_{3,c}$	+	$V_{n,c}$	+	$V_{11,c}$	V_c
	+	+	+	+	+	+	+	+
(ϕ)	$V_{1,\phi}$	$V_{2,\phi}$	$V_{3,\phi}$	+	$V_{n,\phi}$	+	$V_{11,\phi}$	V_ϕ
	+	+	+	+	+	+	+	+
(l) Planing craft	$V_{1,l}$	$V_{2,l}$	$V_{3,l}$	+	$V_{n,l}$	+	$V_{11,l}$	V_l
System total	V_1	V_2	V_3	+	V_n	+	V_{11}	V

Note: $\sum_{a}^{\phi=l} V_{n,\phi} = V_n,\ \sum_{1}^{n=11} V_{n,\phi} = V_\phi$ and $\sum_{1}^{n=11} V_n = \sum_{a}^{\phi=l} V_\phi = V$

Figure 2 Conceptual matrix illustrating the relation between platform configurations and U.S. ocean systems with respect to the value of structural improvement.

TABLE 4

TYPES OF PLATFORM CONFIGURATIONS RANKED BY THE VALUE OF STRUCTURAL IMPROVEMENT

Greatest value:

- Medium monohull

Second greatest value:

- Semisubmersible
- Large monohull
- Bottom-mounted platform

Substantial value:

- Submersible
- Small monohull
- Multihull/SWATH
- Collateral structure
- Tension leg platform
- SES/ACV, hydrofoil

Lesser value:

- Commercial submarine
- Planing craft

Value of work parcels

In a parallel process the value allocated to each platform configuration type was reallocated among the 85 work parcels. The process was very similar but it was made more difficult because of the wide variety of attributes influencing the value share of each R & D effort. The other difficulty was the large number of judgements to be made, about one thousand. The allocation process is illustrated conceptually in Figure 3.

At this point in the evaluations several special considerations were introduced. The SSC has traditionally had nothing to do with the structure of naval submarines so the significant improvement value of these craft was removed leaving only potential commercial submarine applications. A separate analysis revealed that there would be no possible role for concrete as a construction material for any form of transportation craft, be it merchant or naval, and especially if it were one of the high-performance configurations such as the hydrofoil. On the other hand concrete was given competitive consideration for bottom-mounted platforms for which weight is not as critical.

The special considerations also include recognition of the fact that the projects proposed by the LRRP did not cover all useful R & D options for several of the configuration types. The most notable exception was the offshore platforms for which only a few problem areas were covered by project proposals. The structural problems associated with surface effect ships and other high-performance craft also were not covered by a complete set of R & D proposals represented by work parcels, nor were submersibles and commercial submarines. For configuration types for which there was an incomplete set of R & D proposals, the value allocation process was more difficult because the total of the distributed value was unknown. In these cases the value allocation was compared with similar work for which judgements had already been made in assessing the values for monohulls and other configurations for which the R & D proposals were asserted to be complete. These special adjustments are reflected conceptually in Figure 3 by the column totals, which are shown to be less than the values attributable to the configurations in Figure 2.

The results of this evaluation of work parcels are exhibited in Table 5 where the work parcels are ranked in four groups on the basis of the value to the United States accruing from structural improvement.

Although the rankings of work parcels in this table were in fact derived mathematically, the process and the input numbers were, at best, approximations and reflect a considerable exercise of individual judgement. Hence the position of a given work parcel in the list is not to be regarded as having absolute significance. The rankings are valid only in a broad relative sense, in a range, say, of 5 or 10 positions above or below the listed position.

Platform Configurations

Work parcels	(a) Medium monohull	(b) Semisubmersible	(c) Large monohull	(d) Bottom-mounted platform		(ϕ)		(k) Commercial submarine	(l) Planing craft	Work parcel total
L 01	$V_{a,01}$	$V_{b,01}$	$V_{c,01}$	$V_{d,01}$	+	$V_{\phi,01}$	+	$V_{k,01}$	$V_{l,01}$	V_{01}
L(m)	$V_{a,m}$	$V_{b,m}$	$V_{c,m}$	$V_{d,m}$	+	$V_{\phi,m}$	+	$V_{k,m}$	$V_{l,m}$	V_{m}
	+	+	+	+	+	+	+	+	+	+
M(n)	$V_{a,n}$	$V_{b,n}$	$V_{c,n}$	$V_{d,n}$	+	$V_{\phi,n}$	+	$V_{k,n}$	$V_{l,n}$	V_{n}
F(x)	$V_{a,x}$	$V_{b,x}$	$V_{c,x}$	$V_{d,x}$	+	$V_{\phi,x}$	+	$V_{k,x}$	$V_{l,x}$	V_{x}
R(y)	$V_{a,y}$	$V_{b,y}$	$V_{c,y}$	$V_{d,y}$	+	$V_{\phi,y}$	+	$V_{k,y}$	$V_{l,y}$	V_{y}
D(z)	$V_{a,z}$	$V_{b,z}$	$V_{c,z}$	$V_{d,z}$	+	$V_{\phi,z}$	+	$V_{k,z}$	$V_{l,z}$	V_{z}
	+	+	+	+	+	+	+	+	+	+
D27	$V_{a,27}$	$V_{b,27}$	$V_{c,27}$	$V_{d,27}$	+	$V_{\phi,27}$	+	$V_{k,27}$	$V_{l,27}$	V_{27}
Configuration total	V_a	V_b	V_c	$< V_d$	+	$\leq V_\phi$	+	$< V_k$	$< V_l$	$< V$

Figure 3 Conceptual matrix illustrating the relation between work parcels and platform configurations with respect to the value of structural improvement.

TABLE 5

WORK PARCELS RANKED BY THE VALUE OF STRUCTURAL IMPROVEMENT

Greatest Value

F01	Fitness for Service Criteria
F02	Weld Inspection and Repair Standards
R04	Effect of Maintenance on Reliability
D13	Designing for Corrosion
D25	Designing for Inspectability and Maintainability
F09	Design Details to Aid Production
M07	Crack Arrest in Metals
F08	Shipyard Production Control
F03	Ultrasonic Inspection
D03	Casualty Reporting
L11	Combination of Low and High Frequency Loads
L17	Hull Girder Failure, Analysis of Fracture Mode
L15	Hull Girder Collapse, Buckling and Plastic Modes
D24	Optimization Among Design Criteria
F11	Welding Robots and Adaptive Controls
L19	Ice Loads on Ships and Platforms
D15	Viability of Concrete Hulls
F12	Improved Welding Methods and Consumables
L08	Slamming and Bow Flare Impact, Local Response
L14	Hull Girder Collapse, Analysis of Torsion and Torsion-Buckling Modes

Second Greatest Value

F04	Nondestructive On-Line Inspection Technique
F05	CAD/CAM Data Base Formats
D05	Future Needs for Computer-Aided Design (CAD) Methods
D06	Finite-Element Methods (FEM) Computer Program Survey
L01	Directional Sea Spectra
D21	Collisions and Groundings
D07	Wave Data for Design
L12	Experimental Determination of a family of S-N Curves for Typical Ship's Structural Details
M08	Ductile Fracture Mechanics for Ship Steels
F10	Design-for-Production Manual
L07	Slamming and Bow Flare Impact, Hull Girder Response
D09	Impact on Structural Elements, Analysis and Criteria
D23	Ice Loading Criteria

Second Greatest Value (Cont)

F06 Outfit Design System Specification
D17 Transverse-Strength Analysis
L16 Shakedown Analysis of Hull Girders
M09 Joining Copper-Nickel to Steel
D26 Designing to Minimize Green Water Loads
D11 Predicting Propeller-Induced Forces
L18 Local Response to Liquid Cargo Sloshing Impact
D12 Vibrations Prediction Modelling Techniques Improvement
L23 Ship Collisions, Hull Structural Elements, Model Test Program
M10 Effect of Sheathing on Skin Friction
L13 Fatigue Parameter Evaluation
L20 Ship Collisions, Analysis of Hydrodynamic Forces
D10 Predicting Wave-Impact Loads

Substantial Value

L21 Ship Collisions, Large-Scale Experiments
L04 Combined Bending and Torsion Loads on Ships
D27 Vibration Studies Scheduling in the Design Cycle
L05 Static Torsion of Ship's Hull Girder
L29 Added Mass of Locally Vibrating Structure
L31 Validation of Methods for Predicting Higher Mode Frequencies
R05 Guidelines for Scheduled Inspection and Maintenance
D22 Hull Girder Deflection Criteria
R01 Reliability Analysis
R02 Reliability of Structures and Elements
D01 Structural Performance, Monotoring in Service
D02 Reliability of Structure
D04 Computer Program Clearing House
D18 Superimposing Design Loads
D19 Rational Ship Design
D20 Designing Against Fatigue
F07 Review of Industrial Engineering Applications
L24 Analytical Study of Hull Pressures Induced by Intermittent Propeller Cavitation
L25 Analytical Study of Wake, Hull Shape and Propeller-Induced Forces
L26 Study of Wake Harmonics, Model and Full-Scale Measurements
L27 Study of Wake Harmonics Using Instrumented Propeller
L28 Correlation of Calculated and Measured Propeller Blade Pressures

Lesser Value

L22	Ship Grounding Loads, Analysis and Experiment
L30	Ship Vibration Response, Full-Scale Measurements
D16	Designing Concrete Structure, Methods and Criteria
L02	Method for Predicting Loads Induced by Large Non-Linear Head Seas
L10	Local Response to Green Water on Deck
L03	Method for Predicting Moored Vessel Motions and Loads
R03	Structural Failure
D08	Cargo/Structure Interaction
L06	Wave-Induced Springing Response
D14	Designing Arctic-Submarine Structure, Methods and Criteria
M01	Damage Assessment in Concrete
M02	Guidelines for Repair of Marine Concrete Structures
M03	Evaluation of Alternative Reinforcements in Concrete
M04	Develop High Strength-to-Weight Concrete
M05	Fatigue in Marine Concrete Structures
M06	Corrosion in Concrete and Its Inhibition
L09	Hull Girder Response to Green Water on Deck

Importance of work parcels

The foregoing description explains how the U.S. benefit from structural improvement of ships was allocated among the work parcels. For program guidance two more important factors must be introduced; the chance of succeeding with each R & D endeavor and the cost. When these factors are included, a sort of benefit/cost ratio results which we call the "importance" of the work parcel. The list of work parcels ranked in terms of this importance becomes a "best buy" list.

Conceptually this process may be illustrated as follows:

v = Work parcel value

P_s = Probability of success

\$ = Cost

I = Importance of the work parcel

$$I = \frac{v \times P_s}{\$}$$

Judgements regarding probability of success and cost were made by the participants of the LRRP study. These individuals were close to the technical work and far better equipped to make the judgements than were the investigators on this study. The judgements of the LRRP participants were carefully tabulated and statistically averaged. Generally five to ten persons contributed judgements on each factor. For these reasons the averaged values of probability of success and cost were lifted without change from the LRRP printouts and embodied in this report.

The importance of the work parcels is the basis for our recommendations of what should be implemented by the SSC. A listing of the work parcels grouped by importance is given in Table 6, located in the Conclusions and Recommendations section of this report.

Even though we adopted the probability of success and cost data without review or adjustment, we feel that in many cases, especially for cost, the estimates were unrealistic--in fact sometimes by an order of magnitude. In view of this the SSC program planners would be well advised to double check on the values of Table 5 before making decisions. There may be good work parcels there that were overpriced. Conversely, there may be some poor ones high up on the importance ladder because cost estimates were low.

CONCLUSIONS AND RECOMMENDATIONS

This study of structural research and development applicable to United States ocean systems leads to the following conclusions and recommendations:

1. Among the ocean systems examined (see Table 1) it is believed that the nation will benefit most from structural improvements to the Navy/national defense, oil and gas and transportation systems.

2. Analyses revealed that the national value of structural improvement will be greatest for improvements to medium-sized monohulls, semisubmersibles, large monohulls and bottom-mounted platforms, in that order.

   Traditionally the Ship Structure Committee has focused on ships and built its professional and scientific technical constituency to support ship problems. Soil mechanics and quasi-rigidity are examples of technical domains, important for bottom-mounted structures, which have not been addressed in the ship program. Inasmuch as the Ship Structure Committee has only recently received a clear mandate for offshore platforms, there is little in its present or proposed programs bearing on the problems of bottom-mounted or floating platforms. The LRRP study, which was commenced before the decision was made to include bottom-mounted platforms in the SSC research program, reflects this dirth of content.

   Recommendation: We recommend that the Ship Structure Committee formulate a policy regarding its involvement with offshore platforms. Because the SSC appears to be gradually moving into this area, the technical scope of planning should be increased to address problems associated with bottom-mounted platforms.

3. The process of analysis was facilitated by using the concept of platform configurations as a medium for evaluating work parcels.

   Recommendation: We recommend the use of the platform configuration technique in Ship Structure Committee R & D planning.

4. Because concrete ships would consume on the order of 70 percent added fuel due to their greater total weight and save only 10 percent of the steel weight of comparably productive all-steel counterparts, the use of concrete for transportation systems is unlikely. In contrast, the resistance to corrosion may commend concrete as a suitable material for weight-insensitive platforms.

5. Proposed LRRP projects dealing with composite materials were not evaluated because no good applications for composite materials among the platform configurations promising high values from structural improvement could be identified.

6. There were instances in which relevant work of the SSC or the research groups related to the SSC's predecessor Board of Investigation were not cited in support of technical planning. Much valuable research was accomplished in 1942 through 1946 under the stimulus of an incipient national crisis. Many of the results are as useful now as in 1946 and should be made accessible to researchers.

   A complete index including abstracts, and subject--term and author cross-indexes would benefit both the planners and investigators in SSC research programs.

   Recommendation: We recommend that ongoing efforts to establish an index of SSC R & D work be extended to cover the earlier work related to the Navy Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels in 1946.

7. Using the value of improvement attributable to the work parcels (see Table 5), a benefit/cost-type indicator called importance has been derived. The importance of the work parcel is the measure of its attractiveness for implementation, i.e. high importance means SSC "best buys." The work parcels have been ranked in four groups on the basis of their judged importance in Table 6. The ranking by importance in Table 6 yields the "shopping list" for the Ship Structure Committee and it constitutes the principal conclusion of this study.

   Recommendation: We recommend that the SSC employ the work parcel ranking of Table 6 as guidance in formulating its R & D plans. We recommend further that the guidance of Table 6 be used with recognition of the caveats described in the body of this report. Specifically note that Table 6 reflects: 1) subjective judgement and not precise numerical formulation and 2) cost figures are soft, and final decisions would benefit from firmer cost estimates coupled with a review of high value work parcels in the ranking of Table 5.

   In making the foregoing recommendations we have assumed that the SSC will continue two important procedures as it uses these long-range guidelines in choosing its programs and projects. First, it should continue emphasis on literature searches in advance of experimental work. And second, in the frequent cases for which the nature of the experiments is in doubt, it should continue the practice of conducting exploratory projects. These two traditional SSC practices will continue the sound approach to program planning and the efficiency of the SSC R & D efforts.

TABLE 6

WORK PARCELS
RANKED BY IMPORTANCE

Top

F01	Fitness for Service Criteria
F02	Weld Inspection and Repair Standards
D25	Designing for Inspectability and Maintainability
D24	Optimization Among Design Criteria
F09	Design Details to Aid Production
R04	Effect of Maintenance on Reliability
D23	Ice Loading Criteria
F07	Review of Industrial Engineering Applications
M08	Ductile Fracture Mechanics for Ship Steels
L14	Hull Girder Collapse, Analysis of Torsion and Torsion-Buckling Modes
D12	Vibrations Prediction Modeling-Techniques Improvement
D15	Viability of Concrete Hulls
M09	Joining Copper-Nickel to Steel
D09	Impact on Structural Elements, Analysis and Criteria
L17	Hull Girder Failure, Analysis of Fracture Mode
L16	Shakedown Analysis of Hull Girders
D07	Wave Data for Design
M07	Crack Arrest in Metals
F08	Shipyard Production Control
D19	Rational Ship Design

Second

L24	Analytical Study of Hull Pressures Induced by Intermittent Propeller Cavitation
D13	Designing for Corrosion
D27	Vibration Studies Scheduling in the Design Cycle
D06	Finite-Element Methods (FEM) Computer Program Survey
L01	Directional Sea Spectra
D18	Superimposing Design Loads
R05	Guidelines for Scheduled Inspection and Maintenance
L15	Hull Girder Collapse, Buckling and Plastic Modes
L06	Wave-Induced Springing Response
D03	Casualty Reporting

Second (Cont)

L29	Added Mass of Locally Vibrating Structure
F05	CAD/CAM Data Base Formats
L28	Correlation of Calculated and Measured Propeller Blade Pressures
D22	Hull Girder Deflection Criteria
F06	Outfit Design System Specification
F11	Welding Robots and Adaptive Controls
D17	Transverse-Strength Analysis
F04	Nondestructive On-Line Inspection Technique
F10	Design-for-Production Manual
D08	Cargo/Structure Interaction
L31	Validation of Methods for Predicting Higher Mode Frequencies

Third

L25	Analytical Study of Wake, Hull Shape and Propeller-Induced Forces
M10	Effect of Sheathing on Skin Friction
D21	Collisions and Groundings
L18	Local Response to Liquid Cargo Sloshing Impact
L11	Combination of Low and High Frequency Loads
L20	Ship Collisions, Analysis of Hydrodynamic Forces
D04	Computer Program Clearing House
D05	Future Needs for Computer-Aided Design (CAD) Methods
L12	Experimental Determination of a Family of S-N Curves for Typical Ship's Structural Details
L08	Slamming and Bow Flare Impact, Local Response
D10	Predicting Wave-Impact Loads
F03	Ultrasonic Inspection
R03	Structural Failure
L07	Slamming and Bow Flare Impact, Hull Girder Response
L10	Local Response to Green Water on Deck
L04	Combined Bending and Torsion Loads on Ships
F12	Improved Welding Methods and Consumables
L19	Ice Loads on Ships and Platforms
L23	Ship Collisions, Hull Structural Elements, Model Test Program

Fourth

L02	Method for Predicting Loads Induced by Large Non-Linear Head Seas
L03	Method for Predicting Moored Vessel Motions and Loads
D01	Structural Performance, Monitoring in Service
D11	Predicting Propeller-Induced Forces

Fourth (Cont)

L13	Fatigue Parameter Evaluation
L22	Ship Grounding Loads, Analysis and Experiment
D20	Designing Against Fatigue
M02	Guidelines for Repair of Marine Concrete Structures
L30	Ship Vibration Response, Full-Scale Measurements
D02	Reliability of Structure
D26	Designing to Minimize Green Water Loads
L27	Study of Wake Harmonics Using Instrumented Propeller
L26	Study of Wake Harmonics, Model and Full-Scale Measurements
D16	Designing Concrete Structure, Methods and Criteria
D14	Designing Arctic-Submarine Structure, Methods and Criteria
L09	Hull Girder Response to Green Water on Deck
M06	Corrosion in Concrete and Its Inhibition
M04	Develop High Strength-to-Weight Concrete
R01	Reliability Analysis
M01	Damage Assessment in Concrete
L21	Ship Collisions, Large-Scale Experiments
M03	Evaluation of Alternative Reinforcements in Concrete
M05	Fatigue in Marine Concrete Structures
L05	Static Torsion of Ship's Hull Girder
R02	Reliability of Structures and Elements

APPENDIX A

STUDY PROJECT SR 1259

LONG-RANGE RESEARCH PLAN FOR THE SHIP STRUCTURE COMMITTEE*

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INTRODUCTION AND BACKGROUND

In order to develop a comprehensive plan for future ship structural research, the Ship Structure Committee (SSC) sponsored a project to develop a Long-Range Research Plan for ship structural research for the twenty-year period 1980-2000. The main tasks of the project included:

1. The development of position papers presenting the current state of the art in each of the SSC's seven goal areas as reflected in the literature and an assessment of needed or projected research in the subject area.

2. The development of technical forecasts projecting the anticipated effects of technological innovations, resource availability, trends in ship platform types and populations, political trends, legal trends, economic trends, military trends and environmental trends over the period 1980-2000.

3. The development of a methodology to assess the relative benefits and priorities of structural research and development projects.

4. The conducting of two planning workshops in order to gather and assimilate research ideas and recommendations and promote exchanges of information between organizations in and out of government involved in such research.

The first three tasks were concurrent efforts that required detailed literature searches and personal consultation with recognized leaders in the respective fields to develop comprehensive documents. The task 4 effort entailed logistic preparation for conference planning and required the output of the first three tasks. The main objectives of the workshops were:

1. To establish the present state of the technology in each of the ship structural goal areas, identifying problems and possible acceptable solutions.

2. To identify the areas of future maritime need that will require long-range ship structural research efforts.

*No report of this project has been published.

3. To determine and prioritize the most promising avenues of ship structural research.

The first workshop was held at the U.S. Naval Academy in Annapolis, Maryland, on June 24, 25 and 26, 1980, and was attended by approximately 150 people representing industry, academia and involved government organizations. The second workshop took place in Washington, D.C., on December 18-19, 1980, and was attended only by the Session Chairmen, Panel Moderators and Workshop Support Committee of the first workshop.

First Workshop: June 1980

To facilitate group interaction, the general session group at the workshops was broken down into seven panels, one for each of the broad goal areas of the Ship Structure Committee. Each panel, consisting of approximately 15 panel members, was directed by a Session Chairman. These individuals were senior technical people with broad research planning and management backgrounds related to structural research efforts. They led the panel members at the June workshop in review and assessment of the position papers, technical forecasts, and candidate research projects. To assist in clarification and logistic control, a Panel Moderator assisted the Session Chairmen.

Input

To provide a common basis for discussion, working papers were mailed to all participants prior to the first workshop for comment. This set of working papers included the technical forecasts and the position paper for the panel member's assigned goal area. Revised working papers, incorporating all comments and corrections provided by the participants, were completed for use at the workshop sessions and were issued again at the workshop along with forms for proposing candidate projects. A document describing the evaluation procedures to be used for scoring the projects was also provided.

Working Plan

The workshop agenda consisted of concurrent panel sessions addressing each of the following topics:

- State of the Art - The position papers were reviewed for adequacy in order to establish a common basis for discussions.
- Future Trends - The technical forecasts consisting of potential scenarios and trends that may impact structural research requirements were discussed. From these discussions emerged a basis for assessing the applicability of candidate structural research projects to the future needs of the maritime community.

- Project Identification - Previously identified candidate projects were reviewed for adequacy, new projects that reflected the discussions of the position papers and technical forecasts were proposed and projects no longer indicated as worthwhile were set aside. From this process emerged the most significant program areas and the 20 or 30 most significant projects as perceived by the panel for each of the goal areas.

- Project Scoring Method - A review was conducted of the evaluation methodology to be implemented by the participants by mail for scoring the most significant projects.

In addition, general sessions were conducted at the completion of each of the three workshop days. The general sessions consisted of presentations by each of the Session Chairmen on the progress attained in their panel. This exchange provided all the participants with a perspective of the key considerations identified in each of the panel discussions.

Output

The final output of the first workshop was:

1. A final position paper presenting the current state of the art in each goal area, including a description of problem areas.

2. A complete technical forecast indicating the consensus of direction for coordinated research efforts for all goal areas.

3. A description and subjective assessment of the most significant programs and 20-30 most significant projects for each of the goal areas.

Second Workshop: December 1980

Input

The research projects developed at the June 1980 workshop were each numerically rated by the workshop participants in the weeks following according to the evaluation methodology called the project rating system. First the participants rated nine cost/benefit parameters for each project for each of the two time frames -- near term and long term. The results of the ratings were then fed into a computer algorithm that gave overall ratings for each project and then ranked the projects individually in several ways based upon different emphasis parameters. The output results of the first workshop and these rankings provided the inputs to the second workshop.

Working Plan

The second workshop agenda consisted of general sessions for SSC goal area interaction and concurrent panel sessions for individual goal areas in order to:

- Review and Reconcile Workshop I Participants' Output - As part of Workshop I, key problem areas and candidate projects had been identified and a relative order of priority subjectively determined. Subsequent to Workshop I, a quantitative project rating system was implemented via mail. A review and reconciliation of these prioritizations took place for each goal area by the Panel Chairman and Moderator.

- Update LRRP Procedures - The Advanced Concepts Panel Chairman and Moderator prepared a plan for updating the Long-Range Research Plan including: (1) position papers; (2) technical forecasts; and (3) candidate projects and prioritizations.

- Final Rank of Problem Areas, Projects and Programs - Each goal area Chairman and Moderator reviewed the prioritizations to compile and provide a detailed rationale for the final ranked list of projects addressing priority problem areas. All of the given criteria were taken into account. This process included the revision of project descriptions to avoid redundancies, the reconciliation of individual panel needs to adequately reflect ship structural research near-term and long-term needs, and the time-line sequencing of projects from all panels.

Output

The final output of the second workshop was the draft Long-Range Research Plan including:

- Identification of recommended and alternate research programs made up of rational sequences of projects with a summary of their relative benefits and costs.

- The recommended schedule for implementation of the selected programs.

Charts were developed to describe the preferred sequential accomplishment of the projects within the program. Each project description contains information regarding the data prerequisites for the project. Where such prerequisites are minimal or nonexistent, the project can be funded alone to suit available resources.

A matrix of projects and programs was developed in order to provide a comprehensive overview of the entire Program. This matrix shows where each project is used in the various programs, the short-term scores developed by the project rating system, their overall rank and their rank within each goal area. A cursory view of the matrix shows that projects generated in the response, materials and fabrication goal areas are used rarely in programs other than in their own program area. However, the majority of the projects fit into the master programs developed for the reliability and design methods goal areas.

Long-Range Research Needs in the Marine Environment

The long-range needs in ship structural research were developed through a hierarchy of needs from the general to the specific. These have been classified into several levels of need. The first level represents the general, or overall, needs for research and development effort in the marine environment, while the second level represents the specific application of the overall needs to the problems of ship and ocean platform structures.

The first level, or overall needs, is the long-range needs in the marine environment which may be summarized as follows:

1. Energy

- Reduce marine energy consumption
- Improve energy transportation
- Develop new energy sources

2. Safety and Environment

- Improve physical safety in the marine environment
- Develop marine systems to reduce pollution

3. National Defense/National Security

- Develop systems to ensure the freedom of ocean commerce
- Enhance the shipbuilding mobilization base
- Reduce dependence upon foreign sources of strategic materials
- Reduce world food shortages

4. Commercial Development

- Develop new marine transportation opportunities
- Reduce cost of marine transportation

Long-Range Research Needs in Ocean Structures

The needs at the second level are derived from the overall needs and are the long-range research areas of need in ocean structures:

- Investigation of alternatives to today's shipbuilding materials -- their mechanical and chemical properties in marine structures, joining and fabrication techniques, optimal design concepts for their properties, long-term availability and cost data, maintenance requirements, and useful service life
- Behavior of today's materials in new environments and new applications
- Design theory aimed at optimizing fabrication techniques and service performance of ship or platform structures, considering expected service requirements
- Study of realistic ship/ocean dynamics as they affect structural integrity and rigidity for many configurations of ships and platforms
- Study of damage to ships inflicted by collision, grounding, and military action -- failure modes, dynamics, and design measures to minimize damage and probability of failure
- Methods of accurately predicting structural performance and reliability via such methods as modeling and failure analysis
- Robotics and computer-aided fabrication techniques
- Methods to better assure fabrication reliability in oceangoing structures.

Specific Application to Structural Research Programs

It will be the role of those who sponsor research to stimulate some of these advances by addressing a third level of need. The needs are structure research specific and are addressed by the programs that resulted from the study effort.

Program Descriptions: Research Needs for the LRRP

The programs listed here in summary form were based upon problem areas and future requirements identified in the workshops:

Goal Area 1: Loads

- Non-linear Effects
- Experimental Models
- Seaway Representation
- Ice Loads
- Load Combinations

Goal Area 2: Response

- Ultimate Strength of Ship Structures
- Responses to Transient Loads
- Analytical Techniques for Predicting Structural Responses
- Structural Responses to Collision and Grounding Loads

Goal Area 3: Materials

- Marine Concrete Development
- Development of Composites for Marine Utilization

Goal Area 4: Fabrication

- Weld Inspection Methods and Criteria
- Design for Production
- Improved Welding Methods, Equipment and Consumables
- Rational Regulatory Requirements
- Technology Transfer/Diffusion

Goal Area 5: Reliability

- Formulation of a Reliability Model
- Data Feedback into Reliability Model

Goal Area 6: Design Methods

- "Rational" Ship Design Process
- Ship Vibration - Improved Parameter Definition, Criteria and Calculation Methods
- Fatigue of Ship Structural Elements, Criteria, Design Methods and Structural Detailing

APPENDIX A (Cont.)

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LONG-RANGE RESEARCH PLAN FOR
THE SHIP STRUCTURE COMMITTEE

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Acknowledgements

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APPENDIX B

KEY UNITED STATES OCEAN SYSTEMS IN A.D.2000

Seven ocean systems were found to be the dominant potential sources of value to the United States from structural improvement. Following are descriptions of the seven systems as they were assumed to be in A.D. 2000.

Navy

The range of ship types and sizes in the U.S. Navy extends from large carriers (of length about 1,000 ft. and displacement of about 100,000 tons) to small patrol and harbor craft. Combatant ships and craft and, to a lesser degree fleet support ships, are required to be fast and able to operate at high speeds in rough seas. They also must be designed to resist battle damage to the degree feasible for size and type. These requirements strongly influence hull structure configuration, scantlings and choice of materials.

Hull configurations are, and for the foreseable future probably will remain, primarily monohulls. However, a number of advanced concepts having special structural requirements are being introduced into the fleet. Catamarans are in service as submarine rescue ships and oceanographic ships, hydrofoil craft as patrol crafts and gunboats, and air-cushion craft as landing craft. Hydrofoil craft and air-cushion craft require lightweight hull structure for which aluminum is the preferred material; hydrofoil systems require high-strength steels, and the seals or skirts on air-cushion craft present special demands for the development of compliant materials.

Improved structure can be translated into weight savings with benefits measurable in terms of ship size, cost, fuel economy or range, etc., or alternately into improved reliability and, important for combatants, greater damage resistance.

In A.D. 2000 the Navy is projected to include some 600 major ships, 450 of which will be combatants.

Oil and Gas

The offshore oil and gas activities comprise surveying, exploring, development and production. The surveying and exploratory drilling are conducted from platforms ranging from conventional ship types to jack-up rigs with both semi- and full submersibles involved. Development and production are conducted primarily from fixed platforms. The operations are supported by a huge fleet of supply, catering and crew boats in ferry service between the relatively immobile platforms and shoreside depots.

The platforms are mostly complicated space-framed structures. Design of these platforms is a highly sophisticated process. Materials selection, fabrication techniques, construction quality control and maintenance are vital to their survival. Of increasing importance are the severe structural and material requirements that must be met in the design of platforms for arctic service.

For fixed rigs and bottom-mounted storage facilities, the special properties of concrete may be attractive. For the floating rigs the choice of materials will continue to be a compromise determined by construction facilities, mobility needs and the environmental conditions at the sites.

The projection for A.D. 2000 is 3500 offshore platforms with a supporting fleet of 1800 United States vessels.

Structural improvement to this fleet will mean construction and maintenance economies along with increased reliability and safety.

Transportation

The maritime fleet in the year A.D. 2000 is expected to be dominated by containerships, backed up by large numbers of dry-bulk carriers, LNG carriers, tankers and a few barge carriers. Traditional general cargo ships and most other ship types will add only a tiny fraction of the total.

The oceangoing fleet will mesh with far more numerous fleets of towboats, barges and small freighters plying the navigable rivers and the Great Lakes. These craft will benefit from structural improvement, but the relative value to the U.S. is smaller so their special needs have little weight in the planning of R & D.

For the oceangoing fleet the focus is on conventional monohulls. All of the traditional thrusts that have been a part of the Ship Structure Committee R & D program should be considered in the scope of candidates for program planning. These include research on design, materials and fabrication.

The oceangoing portion of the fleet is expected to comprise about 775 vessels in foreign and domestic trade in A.D. 2000.

Benefits from structural improvement will include construction economy and fuel savings for all ships. In addition, there will be an increased carrying capacity for those ships which are not volume limited. Probably the most important benefits will stem from improvements in reliability and maintainability.

Recreation

Recreational craft come in a wide variety of sizes and shapes. Almost every platform configuration is represented. In size they range from luxury yachts displacing hundreds of tons down to small outboard motorboats. The small craft dominate the numbers.

Sales place the pleasure boating area at over $8 billion at present, a significant level in the national economy. There are some 14.5 million pleasure craft in use now and it is projected that there will be 25 million by A.D. 2000.

Fiberglass-reinforced plastic is dominant among the construction materials. However, much aluminum is used and some wood construction continues.

Little formal research and development has been applied to the pleasure craft but there has been much creative experimentation. Thus there is room to improve

but the improvements will be modest and the value to the United States will not be large.

Ocean power generation

There are several options for the generation of energy from the oceans. The one believed to be in major use by A.D. 2000 is ocean thermal energy conversion (OTEC). The projection is that there will be 25 of these plants in operation, each with a capacity of 265 megawatts (electric).

There are unique structural problems involved. The greatest is the cold water pipe (CWP) which may be 100 ft. in diameter and 1,000 ft. to 1,500 ft. long. Other problems include deep ocean moorings and umbilical power transfer cables. The hulls or platforms will be huge structures, and will be complicated by the functional appendages.

These systems offer applications for composites, including reinforced plastics for the CWPs. Prestressed concrete is being considered for the platforms themselves.

Structural improvement beyond the state of the art is required to ensure the very existence of the OTEC plants. The projection of an OTEC fleet is a probability not a certainty.

Fishing, aqua/mariculture

Fishing craft range from 1,000 tons downward, with half being less than five tons in weight. The total amount of structure involved is, however, sizeable because it is expected that the United States fishing fleet will number 20,000 craft in A.D. 2000. The projection calls for 3,500 craft to be under construction and that also represents a sizeable tonnage.

Steel will probably continue to be the material for the larger craft but composites, aluminum and wood will be widely used.

The value to the United States from structural improvement of these craft will be mixed but in most cases modest.

Ocean-sited industrial plants

The only offshore industrial plants forecast by A.D. 2000 are 15 floating nuclear power plants.

These plants will involve large platforms with structural and mooring problems similar to the OTEC plants. They will not involve the large CWPs but otherwise the opportunities for application of advanced structures and materials will be similar to the OTEC units.

The value to the United States of structural improvement is somewhat speculative, as is the probability of the existence of such plants in A.D. 2000.

APPENDIX C

TECHNICAL SITUATION REVIEW

This appendix contains a summary of the highlights of the technical situation from which the R & D programs must emerge. The purpose of the section is to outline the scope of the background material and the genesis of the LRRP programs.

The work of the several groups that met to provide input to the LRRP is the principal substance supporting this study. These groups consisted of experts from the ship research, design, construction, materials and operations communities. The ocean platform community was only sparsely represented.

Background papers, completed by the working groups, consisted of papers for each of the six technology goal areas used by the SSC in its R & D planning. Each paper was organized by a work breakdown structure (WBS) for the particular goal area, and contained for each WBS category: 1) a brief description of work representing the state of the art, 2) a discussion of problem areas and 3) a list of references. Also included was a bibliography annotated with the relevant WBS category numbers. For additional background, reference was made to the 1979 International Ship Structures Congress Proceedings.

Subsequently the groups prepared statements of research needs in each goal area. These statements covered opportunities for improvement, innovation strategies and the rationale for emphasis among technical areas. These statements ended with descriptions of the proposed programs; a total of 21 comprising 190 projects.

This technical situation review is divided into six parts corresponding to "goal areas" used by the SSC in its R & D planning, i.e. loads, response, materials, fabrication, reliability and design. It summarizes the aforementioned LRRP background papers and statements of research needs. The information is abbreviated and accompained by views of the authors. Each of the six sections is organized as follows:

- Role of goal area
- LRRP background material scope and WBS
- Problem areas
- Program rationale

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GOAL AREA 1: LOADS

All types of loads that can be experienced by ships and ocean platforms are included in this category. In some cases loads and response are not clearly separable so that some overlap with goal area 2, response exists. In fact, in the development of work parcels in the present study, the two areas were treated together.

The rather extensive background paper on loads in Volume 3 of the LRRP report is organized by the following WBS which also provides an indication of its scope.

LOADS RESEARCH WORK BREAKDOWN STRUCTURE

1.1 STATIC LOADS

- 1.1.1. Weight
- 1.1.2 Still Water

1.2 CONSTRUCTION AND LAUNCHING

- 1.2.1 Built-in & Residual Stresses
- 1.2.2 Launching Loads
- 1.2.3 Docking Loads

1.3 THERMAL LOADS

1.4 STEADY-STATE WAVE-INDUCED LOADS AND RELATED PHENOMENA

- 1.4.1 Steady-State Wave-Induced Loads
- 1.4.2 Hydrodynamic Forces and Pressure
- 1.4.3 Description of the Sea
- 1.4.4 Ship's Own Wave Train
- 1.4.5 Extreme Waves

1.5 TRANSIENT DYNAMIC LOADS AND HIGH FREQUENCY LOADS DUE TO WAVES AND OTHER SOURCES

- 1.5.1 Bottom Slamming
- 1.5.2 Bow Flare Impact
- 1.5.3 Green Water Impact
- 1.5.4 Whipping
- 1.5.5 Springing
- 1.5.6 Wind Loads
- 1.5.7 Explosion Loads

1.6 CARGO

- 1.6.1 Cargo Sloshing
- 1.6.2 Cargo Shifting

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1.6.3 Thermal Shock from Cargo Damage
1.6.4 Dynamic Loads on Cargo

1.7 ICE

1.8 COLLISION, GROUNDING AND STRANDING LOADS

1.8.1 Collision Loads
1.8.2 Grounding and Stranding Loads

1.9 PROPULSION-AND MACHINERY-INDUCED LOADS

1.9.1 Propeller-Induced Loads
1.9.2 Other Hull-Borne Vibration

1.10 FATIGUE LOADS

1.11 LOAD CRITERIA

1.11.1 Combined Loads
1.11.2 General, Naval, and Commercial Load Criteria
1.11.3 Acquisition and Analysis of Structural Service Data

1.12 MISCELLANEOUS

1.12.1 Loads on Advanced Marine Vehicles

The loads panel of the workshop that resulted in the recommended LRRP projects noted 10 broad problem areas and recommended six major research programs, as follows:

Problem Areas

Primary Areas

- Non-linear motions and extreme loads including both analytical and experimental work
- Sea representation
- Combined loads
- Ice loads
- Collision and grounding loads

Secondary Areas

- Wake prediction for propeller forces
- Expanded propeller force data base
- Loads on cargo

- Combined environmental disturbances

- Additional launch modes such as from floating platforms

Based on the problem areas identified above, the panel proceeded to recommend six major research programs aimed at addressing the problems identified under the primary areas. These were:

1. Implement a long-range fundamental research program into concepts and methods to treat non-linear waves, motions and loads. Such a program covers eleven different items in the loads research WBS, and the panel estimated that the required funding would be about $800,000 spread out over a period of ten years.

2. Plan and carry out model-testing programs for developing a larger data base for analysis and correlation with dynamic and combined loads prediction methods. It was estimated that funding on the order of $600,000 spread over a five-year period would be required.

3. Develop methodologies for combining constituent structural loads elements to establish extreme design loads and fatigue load spectra. This would encompass analytical simulations, experimental data analysis, probabilistic representations, etc., for both ships and offshore structures. A funding level of $250,000 over a period of three years was estimated.

4. Develop a design-oriented statistical representation of the seaway, including different degrees of severity, frequency of occurrence and duration of each sea state, wave-directional characteristics, and combination of wave/wind/current effects. The panel estimated that a funding level of $200,000 over a period of two years would be needed.

5. Plan and implement the development of a valid method for predicting the magnitude of ice loads. This would include development of analytical prediction techniques supported by model-scale tests and full-scale measurements. It was estimated that a funding level of $300,000 over a period of three years would be adequate.

6. Carry out a comprehensive research program in the area of collision and grounding loads. The ultimate objective is to develop practical and valid techniques for predicting the magnitude of these loads. The analytical work must be supported by adequate experimental data collected from large-scale structural model tests (including laboratory structural elements tests plus barge static and dynamic tests). A funding level of $5,000,000 over a period of five years was considered to be necessary.

After defining the six major program areas, the panel proceeded to prepare specific project descriptions grouped under each of the program areas. A total of twenty-four projects were recommended."

GOAL AREA 2: RESPONSE

Goal area two "response", covers the response of structures to the loads of goal area one. As noted in the introductory remarks of goal area one, the two areas overlap to some degree.

The LRRP background material on Response is also extensive. The WBS for this goal area is given below and provides an indication of its scope.

RESPONSE RESEARCH WORK BREAKDOWN STRUCTURE

2.1 RESPONSE TO STATIC LOADS

- 2.1.1 Linear
- 2.1.2 Non-Linear

2.2 RESPONSE TO LAUNCHING AND DOCKING LOADS

- 2.2.1 Ships
- 2.2.2 Offshore Structures

2.3 THERMAL

2.4 RESPONSE TO STEADY-STATE DYNAMIC AND RANDOM LOADS

- 2.4.1 Response to Low Frequency Wave-Induced Loads (Local and Overall)
- 2.4.2 Response to Propeller-Induce Loads (Local and Overall)
- 2.4.3 Response to Engine/Propulsor-Induced Loads (Local and Overall)
- 2.4.4 Response to Wave-Induced Springing
- 2.4.5 Response to Wind-and Current-Induced Loads

2.5 RESPONSE TO TRANSIENT DYNAMIC LOADS

- 2.5.1 Response to Bow Flare Impact (Local and Overall)
- 2.5.2 Response to Green Water (Local and Overall)
- 2.5.3 Response to Slamming (Local and Overall) and Associated Whipping
- 2.5.4 Response to Collision Loads
- 2.5.5 Response to Grounding Loads
- 2.5.6 Response to Blast Loads, Explosions, Underwater Shock
- 2.5.7 Response to Impact Against Floating Objects (Ice and Debris)
- 2.5.8 Response to Sloshing Loads
- 2.5.9 Response to Maneuvering Loads

2.6 FINITE ELEMENT METHOD

2.7 FAILURE MECHANISHMS--FRACTURE, FATIGUE, BUCKLING, COLLAPSE, CREEP

2.8 STRUCTURAL RESPONSE PREDICTION

2.8.1 Superposition
2.8.2 Probabilistic

2.9 CONCRETE STRUCTURES

2.10 VIBRATION PARAMETERS, DAMPING

The Response Panel of the LRRP Workshop noted that in the whole area of ship structural response to loads, there was no part in which the state of the art can be considered as complete or "goal achieved." A nearly complete understanding of the phenomenon of linear response to static loads and response to thermal loads exists. There is room for further knowledge about cyclic loads especially with respect to wave-induced springing and wind-and current-induced loads. There is need for significant research in the area of transient dynamic loads including slamming, collision and impact with ice. Also, there is need for further research in the area of failure mechanisms. These include: fracture, fatigue and buckling. Another area in which there is a substantial deficiency is the knowledge of probablistic methods as applied to structural response. Finally there is a need for much more information on the various forms of damping which influence ship vibration.

The general assessment of the state of the art is reflected in the panel's recommendation for the programs which should receive emphasis in future research and development efforts. These programs are listed below:

- Ultimate Strength of Ship Structures
- Responses to Transient Loads
  - Local responses
  - Global responses
- Analytical Techniques for Predicting Structural Responses
- Structural Responses to Collision and Grounding Loads

In addition to the proposed programs, some additional projects of secondary priority were also proposed:

- A Survey of Available Finite-Element Programs Applicable for Ship Structures
- Structural Response to External Blasts
- Structural Response to Internal Explosions

Although some projects directed at offshore platforms were proposed, consideration of the problems preculiar to these structures (particularly with regard to bottom-mounted platforms) was far from complete.

Other gaps noted in the Response programs are consideration of the transverse strength of catamarans and SWATH, the strength of submarine and submersible pressure hulls and the strength of other elements subject to deep submergence pressure. While these areas are considered important technically, the national importance ratings likely to be attached to SSC work parcels to support them for commercial applications probably would be low.

GOAL AREA 3: MATERIALS

The areas of materials and fabrication together are closely allied to the large-scale construction which is characteristic of marine structures. The needs of the next two decades involve offshore systems to recover oil and minerals at increasing depths, transportation systems of higher speed and greater economy and a growing Navy of increasing effectiveness. Material and fabrication developments will be critical to meeting these needs.

The fundamental properties required of materials to meet marine applications relate to combinations of static and fatigue strength, notch toughness, and corrosion resistance. Advances in the design of structures intended to provide improved performance in projected marine applications can be aided by improving the critical properties of the materials in these structures. Thus higher strength steels can save weight in floating structures or extend the range of depths for platforms and ocean bottom systems. Improved reinforced or prestressed concrete can permit construction economies and enhance resistance to marine life attack. Materials may be combined in new ways to obtain tailor-made properties for particular components of structures, e.g. corrosion-resistant and anti-fouling hull surfaces, wear-resistant foundations and notch-tough members that are dynamically loaded, all to enhance the performance of the system.

The WBS for materials, which follows, is inferred from the content of the background paper narrative:

MATERIALS RESEARCH WORK BREAKDOWN STRUCTURE

3.1 STEEL

- 3.1.1 Steel - Material Properties/Performance
- 3.1.2 Steel - Fracture/Fatigue

3.2 ALUMINUM/TITANIUM

- 3.2.1 Aluminum - Material Properties/Performance
- 3.2.2 Aluminum - Fracture/Fatigue

3.3 REINFORCED PLASTIC

- 3.3.1 Reinforced Plastic Composites - Material Properties/Performance
- 3.3.2 Reinforced Plastic Composites - Fracture/Fatigue
- 3.3.3 Reinforced Plastic Composites - Construction and Repair

3.4 CONCRETE

- 3.4.1 Concrete Material - Material Properties/Performance

3.4.2 Concrete - Fatigue/Fracture
3.4.3 Concrete - Construction/Repair
3.3.4 Ferro - Cement

The problem areas and program rationale for materials is in the Promising Technology section of the main body of this report. See page 14.

GOAL AREA 4: FABRICATION

The improvements that can be developed in the fabrication field have across-the-board significance to the gamut of platform configurations. First, in production design structural details can be chosen to improve the quality and economy of welding assembly. Second, automatic controls, process improvements, and robotics can raise productions rates in welding. Third, recent strides in inspection methods for weldments can assure that imperfections can be held to a chosen size, and fourth, analytical methods can be refined to specify quality control levels on the basis of fitness for purpose rather than on arbitrary and often overconservative grounds. Attainment of many of these goals can be facilitated and speeded by appropriate technology transfer from other industries and countries.

FABRICATION RESEARCH WORK BREAKDOWN STRUCTURE

4.1 DESIGN/PRODUCTION INTEGRATION

4.2 PRODUCTION MANAGEMENT

- 4.2.1 Planning and Production Control
- 4.2.2 Accuracy Control

4.3 COMPUTER-AIDED DESIGN/COMPUTER-AIDED MANUFACTURE

4.4 WELDING AND ALLIED PROCESSES

- 4.4.1 Welding
- 4.4.2 Welding Support Equipment
- 4.4.3 Inspection of Welds

4.5 PRODUCTION PROCESS

- 4.5.1 Material Handling and Load Moving Systems
- 4.5.2 Surface Preparation
- 4.5.3 Cutting Methods
- 4.5.4 Forming Processes

4.6 NON METALS

- 4.6.1 Concrete
- 4.6.2 Fiber-Reinforced Plastic
- 4.6.3 Wood-Laminates

The problem areas and program rationale for fabrication are in the Promising Technology section of the main body of this report. See page 14.

GOAL AREA 5 RELIABILITY

The concepts of reliability and risk underlie all structural design and analysis. They constitute the ultimate mode of expression for structural performance and are essential to quantitative estimating of maintenance costs, system efficiency and safety.

"Reliability analysis is not another method of predicting structural response, even though, using the techniques developed, the response of the structure is predicted in an appropriate way. Further, reliability analysis is not 'continuing everything we're doing already, except re-formulating it in probabilistic terms.' Rather is is an all-encompassing ship structure design methodology which has as its end result not only a structure or a prediction of its response given certain inputs; but, and this is its distinguishing feature, it also addresses and results in a quantitative measure of uncertainty which the designer, the owner, or the classification society may accept or not. It is an effort to determine how much one is not sure about. Obviously, it is philosophically impossible to reach that state because the inputs to this 'uncertainties analysis' are, to an extent, uncertain themselves. It is important to recognize this because reliability analysis has often been touted as a method which largely eliminates engineering 'judgement calls' and totally eliminates the 'factor of safety.' Not so. It only guides the engineer towards making those judgements very consciously, and on smaller ranges of the variables, by forcing a recognition of the uncertainties at each level of the design process."

The LRRP report contains an elaborate statement on the subject of reliability. It commences with a comprehensive work breakdown structure as follows:

RELIABILITY RESEARCH WORK BREAKDOWN STRUCTURE

7.1 OVERVIEW OF STRUCTURAL SAFETY

7.2 SUCCESSFUL APPLICATION IN OTHER FIELDS

7.3 DEFINITIONS FOR RELIABILITY

7.4 FAILURE MODES AND MECHANISMS

7.5 FACTORS AFFECTING STRUCTURAL RELIABILITY IN SHIPS

- 7.5.1 Load Criteria
- 7.5.2 Stress and Strength Criteria
- 7.5.3 Fatigue, Fracture and Corrosion
- 7.5.4 Methods of Analysis
- 7.5.5 Design Methods and Design Details
- 7.5.6 Fabrication and Welding Processes
- 7.5.7 Data Sources and Use of Information
- 7.5.8 Scheduled Maintenance and Its Effects on Reliability
- 7.5.9 Quality Assurance/Quality Control (QA/QC)
- 7.5.10 Cost Economics and Profitability

7.5.11 Collision and Other Failures
7.5.12 Classification Societies

7.6 RELIABILITY MODELS AND ASSESSMENTS IN SHIP STRUCTURES

7.7 INSPECTION TECHNIQUES

7.8 AVAILABLE MATERIALS

7.9 SPECIAL STRUCTURES

7.9.1 Offshore Platforms
7.9.2 Advanced Surface Ships/Fast Craft Submersibles
7.9.3 Bow and Stern Structures
7.9.4 LNG/LPG Carriers
7.9.5 Nuclear Powered Ships
7.9.6 Coastal Structures
7.9.7 Ice Strengthening
7.9.8 Machinery Foundation"

Each part of the work breakdown structure has been developed with a substantial narrative statement describing the state of the art in reliability and supporting these statements with references. In many cases a statement of problems is included.

"We are not going to start designing ship structures using the reliability method tommorrow morning or on January 1, 1987. Nor are we going to totally abandon deterministic approaches at some specific time, or when the reliability method reaches an a priori determined level of maturity. Rather, both methods will co-exist, and in fact do co-exist, each offering its unique feature to the production of better structures. Several papers have been published addressing 'semi-probabilistic' solutions to specific problems. This trend will probably continue, with reliability methodology growing stronger as its yet unexplored and untapped resources become recognized and are reduced from academic intricacies to practical tools. To sustain and reap the benefits of this evolution, two tasks must be fostered: (a) sponsor and guide the research as proposed by the Reliability Panel and modified by other experts and the wisdom of time and (b) effectively transfer the results of the research to the practising naval architect.

The programs developed by the Reliability Panel are:

No.	Program
5A	Formulation of a Reliability Model
5B	Data Feedback Into a Reliability Model

Statistically significant casualty data are essentially unavailable for ships. In one case, in the history of the world, 2700 liberty ships were built. Many of these were similar. But, even for statistical purposes with the liberties, more than a 1,000 must be cast out because they were converted or were basically different to begin with. The statistical sample, thus, was reduced to 1700 and this sample was subjected to competent professional statistical analysis. Probably the situation will never be repeated and thus the casualty records of the future must come from sister ships, groups of two, three and four ships. The statistical techniques for most reliability analysis and forecasting are based on aircraft and automobile experience. The post-mortem records on aircraft come from hundreds of very similar units and on automobiles from tens of thousands of essentially identical units. Attempting to adapt similar statistical techniques to ships is a frustrating endeavor.

Reliability has assumed the stature of a goal area in the SSC program. This tends to make reliability an end in itself, and due to the breadth of application of the concept, it promotes an overlay of duplicating projects.

The SSC probably should consider retaining reliability as the ultimate concept for design but eliminate the promotional distortion occurring because the subject has been made a goal area. Instead it would be wiser to foster promising reliability studies in competition with alternative approaches for each branch of the ship design activity. This would promote the reliability concept as the ultimate approach but cause it to assume a reasonable and appropriate role in each design area where it can be used.

GOAL AREA 6: DESIGN

In developing this study, the authors tended to be more rigid in their interpretation of what would be considered design methods. We limited this goal area to ship structure performance goals, objectives and criteria including design techniques, procedures and their sequencing. We included the necessary synthesis and coordination among all goal areas and with this the data bank management and informational input including such things as casualty reports. Many projects included by the LRRP were distributed to other goal areas because they dealt with investigation and experimentation leading toward the validation of theories relating to physical behavior or system performance; these latter matters being more appropriately under the loads, response, materials and fabrication goal areas.

The basic issues or goals developed by the Design Methods Panel were:

1. To convert state of the art knowledge into design-oriented tools.

2. To promote communications between owners, builders and designers.

3. To develop design tools necessary to accept new, unique structural materials.

4. To develop design tools applicable to unique ship types.

5. To transfer offshore industry knowledge into a structural design community.

6. To insure relevant academic experience in current curricula covering structures.

There is one basic goal which encompasses all of the above, the development of the so-called "rational design method."

"For the purposes of this post-workshop analysis and research program development, it will be assumed that the major umbrella program resulting from the Design Methods Workshop is the formulation and development of a rational and explicit design method based on load prediction, material selection, response analysis, definition of design constraints, selection of a measure of quality, design optimization and appraisal of safety."

The state of the art description pertaining to design methods is comprehensive and starts with a work breakdown structure followd by an amplification of each including background and citing problems. Perhaps the most important problem mentioned was "in effect the state of the art/in converting the researchers state of the art knowledge into user-oriented tools is sorely lagging." The latter is often referred to as the state of the practice.

DESIGN METHODS RESEARCH WORK BREAKDOWN STRUCTURE

6.1 MARINE STRUCTURAL DESIGN--GENERAL

6.2 STRUCTURAL SYSTEM ANALYSIS (DEMAND)

6.2.1 Environment
6.2.2 Loads and Response

6.2.1.1 Still Water Loads
6.2.1.2 Low Frequency Loads
6.2.1.3 High Frequency Loads
6.2.1.4 Other Loads
6.2.1.5 Combination of Loads

6.2.3 Methods of Analysis

6.3 STRUCTURAL DESIGN CRITERIA (CAPABILITY)

6.3.1 Strength Criteria

6.3.1.1 Materials and Fabrication
6.3.1.2 Limit States
6.3.1.3 Fatigue Strength

6.3.2 Evaluation of Demand vs. Capability

6.4 DESIGN OBJECTIVES

6.4.1 Reliabiity
6.4.2 Production
6.4.3 Operation
6.4.4 Optimization
6.5.5 Computational Methods

In spite of the plea to aim at a super rational design method, the work breakdown structure generates problems in accommodating important areas requiring research. These include how to handle corrosion, the need for maintainability and inspectability, the question of monitoring in service, lifetime cost and the whole area of gathering and handling information in support of design methods.

The groups came up with eighteen program areas as follows:

- Design Methods for Non-Metallic Materials
- Analysis of Existing Ships to Calibrate New Design Methods (Hindcasting)
- Standardization of S-N Data (Fatigue)
- Integration of Loads Data with Appropriate Design Tools
- Methods of Superimposing Design Loads
- Tools for Dynamic Analysis of Structural Elements

- Applicability of Fracture Mechanics to Design
- Design tools for Collision Damage Analysis
- Ice Loading Criteria
- Commercial Submarine Design Methods
- Fatigue Design, Details Criteria
- Consideration of Residual Stresses in Design
- Need for Clearing House on Computer-Aided Design Tools
- Further Development of Existing Computer-Aided Design Tools
- Consideration of Corrosion in Design
- Hull Deflection Criteria
- Lateral, Torsional Design Methods
- Feedback of Casualty Data into Design"

These eighteen program areas led to the naming of thirty-four projects from which the work parcels of this study were derived.

APPENDIX D

WORK PARCELS

The work parcels described here consist of mutually supporting sets of R & D tasks which are essential components for achieving specified goals.

Appendix D is in two parts. The first part is a list of work parcel titles and the second part contains brief descriptions of each work parcel. Both parts are arranged by subject. The broad "goal areas" are essentially the traditional categories of the Ship Structure Committee program; loads, response, materials, fabrication, reliability and design. Subordinate subject headings have been selected to suit the work parcel content.

APPENDIX D - PART ONE

LIST OF WORK PARCELS

Loads and Response Goal Areas

Seaway description

L01 Directional Sea Spectra

Rigid body response

L02 Method for Predicting Loads Induced by Large Non-Linear Head Seas
L03 Method for Predicting Moored Vessel Motions and Loads

Elastic response - wave bending

L04 Combined Bending and Torsion Loads on Ships
L05 Static Torsion of Ship's Hull Girder
L06 Wave-Induced Springing Response

Elastic response - wave impact

L07 Slamming and Bow Flare Impact, Hull Girder Response
L08 Slamming and Bow Flare Impact, Local Response

Elastic response - topside loads

L09 Hull Girder Response to Green Water on Deck
L10 Local Response to Green Water on Deck

Failure mechanisms

L11 Combination of Low and High Frequency Loads
L12 Experimental Determination of a Family of S-N Curves for Typical Ship's Structural Details
L13 Fatigue Parameter Evaluation
L14 Hull Girder Collapse, Analysis of Torsion and Torsion-Buckling Modes
L15 Hull Girder Collapse, Buckling and Plastic Modes
L16 Shakedown Analysis of Hull Girders
L17 Hull Girder Failure, Analysis of Fracture Mode

Cargo loads

L18 Local Response to Liquid Cargo Sloshing Impact

Ice loads

L19 Ice Loads on Ships and Platforms

Collision and grounding

L20 Ship Collisions, Analysis of Hydrodynamic Forces
L21 Ship Collisions, Large-Scale Experiments
L22 Ship Grounding Loads, Analysis and Experiment
L23 Ship Collisions, Hull Structural Elements, Model Test Program

Vibration

L24 Analytical Study of Hull Pressures Induced by Intermittent Propeller Cavitation
L25 Analytical Study of Wake, Hull Shape and Propeller-Induced Forces
L26 Study of Wake Harmonics, Model and Full-Scale Measurements
L27 Study of Wake Harmonics Using Instrumented Propeller
L28 Correlation of Calculated and Measured Propeller Blade Pressures
L29 Added Mass of Locally Vibrating Structure
L30 Ship Vibration Response, Full-Scale Measurements
L31 Validation of Methods for Predicting Higher Mode Frequencies

Material Goal Area

Concrete damage and repair

M01 Damage Assessment in Concrete
M02 Guidelines for Repair of Marine Concrete Structures

Improvements in reinforced concrete

M03 Evaluation of Alternative Reinforcements in Concrete

M04 Develop High Strength-to-Weight Concrete
M05 Fatigue in Marine Concrete Structures
M06 Corrosion in Concrete and Its Inhibition

Crack arrest technology

M07 Crack Arrest in Metals
M08 Ductile Fracture Mechanics for Ship Steels

Copper - nickel sheathing

M09 Joining Copper-Nickel to Steel
M10 Effect of Sheathing on Skin Friction

Fabrication Goal Area

Inspection criteria and fitness for purpose

F01 Fitness for Service Criteria
F02 Weld Inspection and Repair Standards
F03 Ultrasonic Inspection
F04 Nondestructive On-Line Inspection Technique

CAD/CAM for fabrication of platforms and ships

F05 CAD/CAM Data Base Formats
F06 Outfit Design System Specification

Production control

F07 Review of Industrial Engineering Applications
F08 Shipyard Production Control

Design for production

F09 Design Details to Aid Production
F10 Design-for-Production Manual

Welding development

F11 Welding Robots and Adaptive Controls
F12 Improved Welding Methods and Consumables

Reliability Goal Area

R01 Reliability Analysis
R02 Reliability of Structures and Elements

R03 Structural Failure
R04 Effect of Maintenance on Reliability
R05 Guidelines for Scheduled Inspection and Maintenance

Design Goal Area

General

D01 Structural Performance, Monitoring in Service
D02 Reliability of Structure
D03 Casualty Reporting
D04 Computer-Program Clearing House
D05 Future Needs for Computer-Aided Design (CAD) Methods
D06 Finite-Element Methods (FEM) Computer-Program Survey

Structural system analysis - low frequency loads

D07 Wave Data for Design
D08 Cargo/Structure Interaction

Structural system analysis - high frequency loads

D09 Impact on Structural Elements, Analysis and Criteria
D10 Predicting Wave-Impact Loads
D11 Predicting Propeller-Induced Forces
D12 Vibrations Prediction Modeling-Techniques Improvement

Structural system analysis - methods of analysis

D13 Designing for Corrosion
D14 Designing Arctic Submarine Structure, Methods and Criteria
D15 Viability of Concrete Hulls
D16 Designing Concrete Structure, Methods and Criteria
D17 Transverse-Strength Analysis
D18 Superimposing Design Loads
D19 Rational Ship Design

Structural system analysis - other loads

D20 Designing Against Fatigue
D21 Collisions and Groundings

Structural design criteria

D22 Hull Girder Deflection Criteria
D23 Ice Loading Criteria

Design objectives

D24 Optimization Among Design Criteria
D25 Designing for Inspectability and Maintainability

Design process

D26 Designing to Minimize Green Water Loads
D27 Vibration Studies Scheduling in the Design Cycle

APPENDIX D - PART TWO

DESCRIPTION OF WORK PARCELS

Loads and Response Goal Areas

L01 DIRECTIONAL SEA SPECTRA

Objective: A plan for routine measurement of seaways to obtain directional spectra.

(a): Evaluation/Comparison of Procedures for Measuring Directional Characteristics of Seaways

Method: Evaluation of current state of the art methods of measuring seaways to extract directional data. Employing direct comparison of data from sources such as radar, stereophotography, wave gauge arrays, hindcasting.

(b): Plan for Routine Measurement of Seaways to Obtain Directional Spectra

Method: Assess present techniques, evaluate error sources; recommend techniques for obtaining measurements; recommend methods for reducing, presenting and storing data; estimate costs.

Cost/Duration: $130K, 2 years

L02 METHOD FOR PREDICTING LOADS INDUCED BY LARGE NON-LINEAR HEAD SEAS

Objective: A method for predicting wave-induced loads on a ship in large non-linear form head seas.

Method: Theoretical development beyond present linear models, accounting for effect of ship passage thru waves, such as: deformation of wave, change in hull water plane area with time, ship's own wave train, etc.

Cost/Duration: $165K, 2 years

L03 METHOD FOR PREDICTING MOORED VESSEL MOTIONS AND LOADS

Objective: The titled method

Method: Analysis of motions and loads in extreme seas (ultimate survival case) supported by model tests and full-scale measurements, considering forces due to waves, wave drift, currents and wind on moored vessels or platforms, particularly those having bluff hull forms.

Cost/Duration: $160K, 1 year

L04 COMBINED BENDING AND TORSION LOADS ON SHIPS HULL GIRDER

Objective: Verification of existing theory

Method: Hydrodynamic model tests using articulated models instrumented to measure motions, pressures, bending moments (2 axes), torsion, etc.

Cost/Duration: $200K, 1½ years

L05 STATIC TORSION OF SHIP'S HULL GIRDER

Objective: Improved analytic/numerical methods to predict deformation and stress distribution for ore carriers, container ships, etc. under torsion.

Method: Full-scale static torsion test of suitable ship and comparison with FEM analysis.

Cost/Duration: $500K, 3 years

L06 WAVE-INDUCED SPRINGING RESPONSE

Objective: Improved methods of prediction of springing response.

(a): Effect of Hull Shape on Wave-Induced Springing

Method: Analytical study to evaluate magnitude of variations in added mass, damping, buoyancy loads related to realistic variations in bow and stern shape and the corresponding springing response.

(b): Method for Prediction of Springing

Method: Investigate the wave-induced excitation and hydrodynamic damping associated with springing. Analytical study utilizing data from full-scale springing measurements on the S. J. CORT, U. of Michigan model test work and the results of component a to provide basis for improved predictive methods.

Cost/Duration: $160K, 2 years

L07 SLAMMING AND BOW FLARE IMPACT, HULL GIRDER RESPONSE

Objective: Improved method of predicting hull girder response to wave-induced bow impact loads.

(a): Bow Impact Loads - Model Test and Correlation with Theory

Method: Tests on articulated hydrodynamic models in "locked" and "flexible" modes and correlation with available theory for slamming and bow flare impact loads.

(b): Method of Calculating Hull Girder Response to Bow Impact Loads.

Method: Development of analytical/computational model for the titled problem and verification using available model and full-scale data including the results of component a above.

Cost/Duration: $400K, 3 years

L08 SLAMMING AND BOW FLARE IMPACT, LOCAL RESPONSE

Objective; Development and verification of improved methods of predicting the response of local bottom and bow flare structure to wave-induced impact loads.

(a): Slamming and Bow Flare Impact, Local Response, Full-Scale Measurements

Method: Full-scale experimental program to measure local response of plating and plate-stiffener combinations. Associated local dynamic pressures and overall rigid body motions should also be measured.

(b): Slamming and Bow Flare Impact, Local Response, Model Tests and Analytical Model Development

Method: Analytical development of an elasto-plastic model. Validation by numerical calculations compared with structural

model tests at large enough scale to permit accurate modelling of details (¼ scale or greater), and L08 results if available.

Cost/Duration: $320K, 3 years

L09 HULL GIRDER RESPONSE TO GREEN WATER ON DECK

Objective: Analytical/computational method for response of hull girder associated with shipping of green water.

Method: Development of elastic model for title problem and validation, if feasible, with full-scale data. Results from L07 may provide framework.

Cost/Duration: $150K, 2 years

L10 LOCAL RESPONSE TO GREEN WATER ON DECK

Objective: Analytical/computational method for treatment of local structural response to green water topside loads.

Method: Develop an elasto-plastic modelling method for the title problem.

Cost/Duration: $150K, 2 years

L11 COMBINATION OF LOW-AND HIGH-FREQUENCY LOADS

Objective: Analytical methods for titled problem aimed at (i) estimating extreme values and (ii) fatigue load spectra.

Method: (i) Determine phasing of low-and high-frequency loads based on full-scale data and theoretical predictions. Determine correlation coefficients for combining maximum values of low and high frequency ranges of long-term predictions. Include consideration of combined primary, secondary and tertiary stresses. (ii) Similarly develop improved method for producing load or stress spectra suitable for analysis of fatigue as follow-on to existing SSC project (SR-1254).

Cost/Duration: $230K, 3 years

L12 EXPERIMENTAL DETERMINATION OF A FAMILY OF S-N CURVES FOR TYPICAL SHIP'S STRUCTURAL DETAILS

Objective: The titled S-N curves.

Method: Similar to American Welding Society curves and work by off-shore industry on tubular joints. Effects of "overstrain" and endurance limit to be considered in design of tests. This work would provide link between two existing SSC projects on fatigue dealing with methodology and load spectrum, and continue experimental work started under SSC sponsorship.

Cost/Duration: $400K, 3 years

L13 FATIGUE PARAMETER EVALUATION

Objective: Determination of the effects and importance of such variables as mean stress, material properties, residual stresses and thermal stresses in predicting fatigue performance of welded structural details.

Method: Using results of L12, hindcast effects of variables enumerated above on actual details.

Cost/Duration: $300K, 3 - 5 years

Prerequisites: Appendage to L12.

L14 HULL GIRDER COLLAPSE, ANALYSIS OF TORSION AND TORSION BUCKLING MODES

Objective: Determine load carrying capacity of ship's hull girder in modes of torsional collapse and torsion combined with compressive buckling. Possible coupling with other failure modes also to be considered.

Method: Analytical study. Follow-on to SSC 299

Cost/Duration: $68K, 1 year

L15 HULL GIRDER COLLAPSE, BUCKLING AND PLASTIC MODES

Objective: Experimental verification and calibration of analytical methods treating hull girder failure by a combination of buckling and plastic deformation.

Method: Work to proceed in two stages (i) testing of small models where analytical solutions exist, (ii) testing of larger scale models resembling actual ship structures.

Cost/Duration: $250K, 1½ years

L16 SHAKEDOWN ANALYSIS OF HULL GIRDERS

Objective: Further clarify the role of shakedown in the overall failure mechanism of hull girders and develop new or improved methods for ship structures.

Method: Analytical study

Cost/Duration: $80K, 1 year

L17 HULL GIRDER FAILURE, ANALYSIS OF FRACTURE MODE

Objective: To determine the strength of ship's hull girder considering presence of fatigue crack(s).

Method: Analytical study of failure under single ultimate moment application for cracks of varying severity. Recommendations for follow-on experimental work.

Cost/Duration: $80K, 1 year

L18 LOCAL RESPONSE TO LIQUID CARGO SLOSHING IMPACT

Objective: Analytical/computational method for cargo tank structure, especially for LNG chemical carriers.

Method: An elasto-plastic modelling method is envisioned, to be validated by experimental data at approximately 1/10 scale.

Cost/Duration: $175K, 2 Years

L19 ICE LOADS ON SHIPS AND PLATFORMS

Objective: Method of estimating magnitude of time history of ice loads on moving vessels and fixed platforms.

(a): Full-Scale Ice Load Measurements

Method: Review existing data. Evaluate loads imposed on ships hulls and platforms by ice. Establish operating criteria (situations). Conduct ice strength measurements. Conduct ice strength load/impact studies.

(b): Methodology for Predicting Ice Loads

Method: Analytical study of titled problem. Utilize data from L19.

(c): Ice Load Simulation, Model Testing

Method: Design and conduct model experiments and correlate results with full-scale measurements and analytical predictions.

Cost/Duration: $630K, 3 years

L20 SHIP COLLISIONS, ANALYSIS OF HYDRODYNAMIC FORCES

Objective: Determine hydrodynamic forces involved in ship collisions.

Method: Analytical and experimental study. Tests envisioned for 3 models, various drafts, speeds and angles of impact. Results to be in parametric form for use in analysis or design studies.

Cost/Duration: $150K, 1 year

L21 SHIP COLLISIONS, LARGE-SCALE EXPERIMENTS

Objective: To validate simple and complex methods of design and analysis for low speed ship collisions by acquiring loading and damage data.

Method: Large- or full-scale ship collision experiments are estimated to cost $3000K or more. The USCG has plans to carry out such experiments (See USCG Report CG-D-21-80, March 1980 "Vessel Collision Damage Resistance - Development of Preliminary Test Plan for Large/Full-Scale Vessel Collision Tests"). The scope of this work parcel is to monitor and evaluate the USCG project if it is undertaken.

Cost/Duration: $30K, 1 year.

Prerequisite: USCG collision project

L22 SHIP GROUNDING LOADS, ANALYSIS AND EXPERIMENT

Objective: To provide an analytical tool for predicting grounding loads as a function of ship bottom structure, sea bottom soil or obstacle characteristics and ship speed.

Method: Develop analytical simulation of grounding phenomenon including consideration of ship geometry, ship/soil interaction and soil/bottom mechanical properties. Design and test a procedure to measure grounding loads as a function of ship/soil characteristics.

Cost/Duration: $200K, 2 years

L23 SHIP COLLISIONS, HULL STRUCTURAL ELEMENTS, MODEL TEST PROGRAM

Objective: To provide an experimental data base for use in collisions and damage - resistance analysis.

Method: Conduct laboratory tests of ship structural elements: (a) using static loading (b) using dynamic loading. Models should be no smaller than ½ scale and incorporate typical ship steel plates and shapes fabricated using typical shipyard practice, and embody various configurations of plates, stiffened panels and end connections.

Cost/Duration: $275K, 1½ years

L24 ANALYTICAL STUDY OF HULL PRESSURES INDUCED BY INTERMITTENT PROPELLER CAVITATION

Objective: To determine the accuracy of Massachusetts Institute of Technology-Stevens Institute of Technology (MIT-SIT) program for such pressures compared with measurements made at the Swedish Marine Research Center (SSPA), Goteborg, Sweden.

Methods: Programs exist but must be exercised. Data provided by SSPA has been compared with results of MIT-SIT programs. Further validation using data from other sources is required. Note ongoing USN work in this area.

Cost/Duration: $40K, 1 year

L25 ANALYTICAL STUDY OF WAKE, HULL SHAPE AND PROPELLER-INDUCED FORCES

Objective: Determine the influence of stern geometry on wake pattern and how wake affects propeller loads and hull pressures.

Method: Analytical study using existing wake data and existing programs for calculating hull forces with and without cavitation. Should be coordinated with ongoing USN efforts.

Cost/Duration: $75K, 1½ years

L26 STUDY OF WAKE HARMONICS, MODEL AND FULL-SCALE MEASUREMENTS

Objective: Determine the effects of scale and hull geometry on harmonics of wake.

Method: Model and full-scale measurements of wake for 3 ships using laser doppler velocity meter techniques. Compare results to determine effects of Reynolds number and hull geometry. Measure hull surface pressures. Derive influence of propeller in nominal wake field.

Cost/Duration: $40K, 2 years

L27 STUDY OF WAKE HARMONICS USING INSTRUMENTED PROPELLER

Objective: Increase understanding of the spatial harmonics of ship's wake using pressure gauges along the span of one blade of a propeller in both model and full scale.

Method: (see objective) Tests of model corresponding to full-scale propeller to be instrumented should be successfully completed first to demonstrate one-to-one relationship between pressure gauge output and each wake harmonic.

Cost/Duration: $250K, 2 years

L28 CORRELATION OF CALCULATED AND MEASURED PROPELLER BLADE PRESSURES

Objective: To validate existing unsteady blade-pressure program.

Method: Data from German large-scale tests in air are available. These to be compared with calculated values using existing theory and computer program.

Cost/Duration: $50K, 1 year

L28 (Cont.)

References:

- E. A. Weitendorf. "Cavitation and Influence on Induced Hull Pressure Amplitudes." Symposium on Hydrodynamics of Ship and Offshore Propulsion Systems. Det Nordske Ventas, Oslo, Norway 1977.
- K. Kienappel. "Unterschung zer Messung Interstationaerer Drucke in Rotvienden." AVA report DLF-FB-77-43, 1977.

L29 ADDED MASS OF LOCALLY VIBRATING STRUCTURES

Objective: To obtain data on added mass coefficients applicable to vibratory behavior of local structure such as bulkheads, web frames and local bottom structure.

Method: Problem could be approached experimentally or analytically. If analytically, it should be substantiated by a small experimental program. Should consider cases with fluid on one or both sides of the vibrating structure.

Cost/ Duration: $100K, 2 years.

L30 SHIP VIBRATION RESPONSE, FULL-SCALE MEASUREMENTS

Objective: To improve the representation of damping in hull girder vibration calculations.

Method: Full-scale testing (shaker). Will require rental of equipment and loan of or access to, several ships. To consider structural hydrodynamic and cargo influences on total damping. Tests to be designed to allow extraction of definitive information on natural frequencies, mode shapes and damping.

Cost/Duration: $500K, 3 years

L31 VALIDATION OF METHODS FOR PREDICTING HIGHER MODE FREQUENCIES

Objective: Either validate or provide guidance for extending FEM methodology for the undamped case.

Method: Correlation of computer analysis with full-scale data from L30.

Cost/Duration: $125K, 1½ year

Prerequisite: L30

Materials Goal Area

M01 DAMAGE ASSESSMENT IN CONCRETE

Objective: To improve NDT equipment and procedures for evaluating the extent of damage in concrete, investigate damage mechanisms, and prepare rational guidelines for damage assessment.

Method: Experimental development of equipment and procedures starting with existing techniques and examination of potential of new technology.

Cost/Duration: $400K, 5 years

M02 GUIDELINES FOR REPAIR OF MARINE CONCRETE STRUCTURES

Objective: To provide standardized repair techniques that reduce time and cost, and prepare a handbook.

Method: Experimental development of standardized repair techniques matched to nature of damage using existing technology.

Cost/Duration: $125K, 2 years

M03 EVALUATION OF ALTERNATIVE REINFORCEMENTS IN CONCRETE

Objective: To provide alternate methods of reinforcing concrete to improve load bearing and impact properties.

Method: Experimental testing of material properties of concrete reinforced with fibers, ferrocement, etc.

Cost/Duration: $600K, 5 years

M04 DEVELOPMENT OF HIGH STRENGTH-TO-WEIGHT CONCRETE

Objective: To provide high strength, lightweight concrete that is competitive with steel in useful load-to-total-weight ratio.

Method: Experimental study of properties of candidate materials and new materials with strength-weight ratios similar to steel.

Cost/Duration: $350K, 1½ years.

M05 FATIGUE IN MARINE CONCRETE STRUCTURES

Objective: To identify fatigue problem areas with emphasis on fatigue in shear and in reinforcement.

Method: Experimental investigation of fatigue in prestressing tendons, fibers, and re-bars including a natural seawater environment.

Cost/Duration: $1,500 K, 3 years

Prerequisite: M04

M06 CORROSION IN CONCRETE AND ITS INHIBITION

Objective: To identify potential corrosion problems and develop corrosion protection methods, resulting in corrosion control guideline manual.

Method: Literature review, investigation of corrosion inhibitors and their requirements.

Cost/Duration: $200K, 1 year

M07 CRACK ARREST IN METALS

Objective: To develop damage-tolerant structural configurations that arrest unstably running cracks.

Method: Evaluate effects of large inertial loads on crack arrest by stringers and plates, and conduct large-scale tests as needed on stringer-stiffener structure.

Cost/Duration: $280K, 3 years

M08 DUCTILE FRACTURE MECHANICS FOR SHIP STEELS

Objective: To apply the newly developing fracture mechanics technologies for ductile metals to ship steels.

Method: Analytical study of new ductile fracture mechanics concepts and small-scale experimental confirmation.

Cost/Duration $60K, 2 years

M09 JOINING COPPER-NICKEL TO STEEL

Objective: To provide a production process for joining Cu/Ni sheaths to steel..

Method: Experimental development of effective methods of joining these dissimilar alloys.

Cost/Duration: $100K, 1½ years.

Prerequisite: Existing support projects.

M10 EFFECT OF SHEATHING ON SKIN FRICTION

Objective: To increase operating efficiency by reducing fuel consumption gained by lowering skin friction of hulls free of fouling.

Method: Experimental demonstration of benefits of sheathing to skin friction on a 200-ft. coastal tanker and experiments to optimize coating system.

Cost/Duration: $250K, 3 years.

Fabrication Goal Area

F01 FITNESS FOR SERVICE CRITERIA

Objective: To minimize weld repair via the establishment of national weld acceptance standards based on fitness for service criteria.

Method: Establish inspection acceptance standards based on fracture mechanics principles applied to weld defect types and sizes.

Cost/Duration: $60K, 1 year

F02 WELD INSPECTION AND REPAIR STANDARDS

Objective: To reduce the incidence of unnecessary weld repairs

Method: A review of structural performance of post-war ships and NDT experience.

Cost/Duration: $60K, 1 year

Prerequisite: F01

F03 ULTRASONIC INSPECTION

Objective: To produce standards and improved procedures for the ultrasonic inspection of marine structures.

Method: An experimental development program to adapt improved ultrasonic techniques to weld inspection.

Cost/Duration: $1,000K, 5 years

F04 NONDESTRUCTIVE ON-LINE INSPECTION TECHNIQUE

Objective: To provide means of continuous monitoring of production welding.

Method: Evaluation of existing on-line inspection devices, such as acoustic emission, ultrasonic, holographic methods. (Work of the Electric Power Research Institute should be consulted.)

Cost/Duration: $250K, 2 years

Prerequisite: F02

F05 CAD/CAM DATA BASE FORMATS

Objective: To provide a consensus for a format of CAD/CAM-generated structural information for easy transfer from designer to lead to follow yards and for data retrieval to monitor production.

Method: Develop a format specification of CAD-generated structural digital information for efficient transfer between designers and yards.

Cost/Duration: $220K, 2 years

F06 OUTFIT DESIGN SYSTEM SPECIFICATION

Objective: To provide user and systems specifications for a CAD system embodying prevailing or contrived component, arrangement and system standards.

Method: Use industry consultants to develop user specifications and a systems analyst for the systems specifications.

Cost/Duration: $210K, 1 year

F07 REVIEW OF INDUSTRIAL ENGINEERING APPLICATIONS

Objective: An informational review of the logic and principles of I.E. that can be applied to shipbuilding.

Method: Generation of a short informational report to the industry .

Cost/Duration: $40K, ½ year

F08 SHIPYARD PRODUCTION CONTROL

Objective: To define the logic and principles of quantitative production control techniques including control of materials.

Method: Approach is to seek integration with CAD/CAM and other management information systems. An industry application manual should result.

Cost/Duration: $250K, 2 years

Prerequisite: F07

F09 DESIGN DETAILS TO AID PRODUCTION

Objective: To identify simple or cheap alternative design details from the perspective of production efficiency.

Method: A review of current data and interviews with interested and knowledgeable personnel to develop design improvements.

Cost/Duration: $60K, 1 year.

F10 DESIGN-FOR-PRODUCTION MANUAL

Objective: To provide a comprehensive design guidance manual to illustrate design methods and details leading to simplicity and efficiency of fabrication with no compromise of structural function.

Method: Gathering of state of the art data from here and abroad, preparation of a draft manual, collection of comments, and publication of a manual.

Cost/Duration: $75K plus $25K per year for revisions.

Prerequisite: F09

F11 WELDING ROBOTS AND ADAPTIVE CONTROLS

Objective: To improve welding quality and productivity by in-process sensing devices and adaptive control techniques, including robotic equipment.

Method: Laboratory work, computer simulations, and equipment development.

Cost/Duration: $500K, 5 years

F12 IMPROVED WELDING METHODS AND CONSUMABLES

Objective: To provide and qualify for shipyard qualification, improved electrodes and filler metals for welded fabrication of marine structures, providing enhanced mechanical properties, high deposition rates and low levels of contaminants.

Method: Laboratory development work

Cost/Duration: $1,000K, 5 years

Reliability Goal Area

R01 RELIABILITY ANALYSIS

Objective: To provide a concept, model and procedures to assess and express reliability levels.

(a): Model, Concept and Input

Method: Extend and modify "shoreside" existing reliability models to ship applications.

(b): Technology Transfer from Other Sources

Method: Obtain and apply model information from other sources.

(c): Model Verification Test Plan

Method: Exercise model to determine sensitivity to input variations. Develop set of critical situations to be evaluated by test and by service.

(d): Validation by Service Records

Method: Check reliability model against actual ship service records to bracket validity of predictions.

Cost/Duration: $1,165K, 5 years

R02 RELIABILITY OF STRUCTURES AND ELEMENTS

Objective: To increase the realism of ship-structure reliability analysis by providing quantitative structural performance data.

Method: Design, fabricate and test structures and elements to provide data which will strengthen the credibility of reliability analysis based on other types of data such as ship service records.

Cost/Duration: $10,000K, 6 years

Prerequisite: The reliability model of work parcel R01 is a prerequisite to the test plan of this work parcel, R02.

R03 STRUCTURAL FAILURE

Objective: To improve the estimating of ultimate hull strength through improved response models and failure mode criteria.

(a): Modes and Criteria

Method: Identify modes of failure and associated strength criteria. Define environmental effects and operational impairment for 4 types of ships.

(b): Frigid Environment Influences

Method: Develop special information regarding the influence of low temperature, ice loading and very rough seas on failure modes and criteria.

(c): Strength versus Failure Mode

Method: Verify analytically the performance of failure response models and refine the models to reduce the variability of the predictions of ultimate hull strength.

Cost/Duration: $570K, 5 years

R04 EFFECT OF MAINTENANCE ON RELIABILITY

Objective: To relate the frequency of inspection and maintenance to the structural failure rate.

Method: Seek groups of ships in similar service for which the frequencies of scheduled inspection and maintenance are naturally different. Attempt to correlate frequency of maintenance with failure rate.

Cost/Duration: $80K, 1 year

Prerequesite: This study requires a special base of data involving a range of inspection intervals and a tie to casualty data.

R05 GUIDELINES FOR SCHEDULED INSPECTION AND MAINTENANCE

Objective: To provide procedures for the designer to guide structural inspectors to the critical structural areas, tell them what to look for, how frequently to inspect, how to know when repairs are needed and the routines for reporting.

Method: Inventory the most likely places for fracture, buckling, corrosion, impact damage and deformations. Review prevailing criteria for acceptable deterioration and damage. Summarize in handbook form.

Cost/Duration: $80K, 1 year

Design Goal Area

D01 STRUCTURAL PERFORMANCE, MONITORING IN SERVICE

Objective: To determine the potential benefits of continuously monitoring structural parameters throughout the life of the vessel.

Method: Utilizing techniques developed in the aircraft industry, attempt to measure remaining structural capability such as residual fatigue life. Consider the impact on inspection requirements.

Cost/Duration: $350K, 3 years

D02 RELIABILITY OF STRUCTURE

Objective: To establish reliability criteria for ship structural elements.

(a): Reliability Hindcasting Methodology

Method: Select candidate vessels for reliability hindcasting study. Develop analytical methodology of relating the designs to their structural performance.

(b): Reliability criteria for ship structural elements

Method: Employing the results of component a, delineate criteria which will engender successful ship designs.

Cost/Duration: $52K, 5 years

Prerequisite: Availability of an ample record of ship histories.

D03 CASUALTY REPORTING

Objective: To increase the benefits from casualty post-mortem analysis.

(a): Feedback from Structural Casualties

Method: Review prevailing casualty reporting and investigating systems, attempt to improve the technical content and accessibility of the data.

(b): Feedback from Inspection of Structures

Method: Review prevailing systems for investigating incipient failures detected during inspection. Prepare recommendations for modifying reporting systems so as to make the failure input more useful.

(c): Alerts to Designers

Method: Recommend means to acquaint ship designers with the results of failure analysis.

Cost/Duration: $500K, 3 years

D04 COMPUTER-PROGRAM CLEARING HOUSE

Objective: To establish a center for exchange of computer programs and computer-aided design tools related to all facets of ocean-structures design.

Method: Initially document existing computer programs and subsequently acquire new programs.

Cost/Duration: $200K/year for two years dropping to $50K/year thereafter, continuously.

D05 FUTURE NEEDS FOR COMPUTER-AIDED DESIGN (CAD) METHODS

Objective: To provide a long-range plan for the development of CAD programs.

Method: Systematically survey and evaluate the long-term need for computer-aided design methods for ship structure. Formulate schedules for the development of new programs, etc.

Cost/Duration: $400K, 2 years, followed by periodic updates.

D06 FINITE-ELEMENT METHOD (FEM) COMPUTER PROGRAM SURVEY

Objective: To provide additional FEM computer programs as required.

Method: Survey all available linear and non-linear finite element programs applicable to ship structure. Make recommendations for additional program development.

Cost/Duration: $45K, 1 year

D07 WAVE DATA FOR DESIGN

Objective: To provide improved spectral ocean wave models (SOWM) and criteria that can be used in early design stages and in final design and meeting classification requirements.

(a): Appraisal of Data Needs

Method: Appraise the data needs for vehicle types in terms of frequencies and point or directional type data.

(b): Statistical Models of Seaways

Method: Evaluate available SOWM formats. Strive to find means to represent: i) extremely severe seas (Douglas scale 8 and above) entailing highly non-linear waves, ii) moderately severe seas (Douglas scale over 5) involving asymmetries not accommodated in available models and iii) seaways in shoaling water involving highly non-linear behavior.

(c): Interrelation Among and Superposition of Oceanic Environmental Factors

Method: Develop design criteria based on the probability of simultaneous occurrence of wind, waves and currents. Produce load scenarios for design and operations.

(d): Re-formating SOWM for Different Design Levels

Method: Develop semi-probabilistic models for early design. These can involve point-type spectra and limited ocean areas. Develop more elaborate models for final design and meeting classification requirements. These would involve extensive or all-ocean areas and directional spectra.

(e): Formating Data Bases

Method: Re-format available wave data to suit new SOWMs and generate cards, tapes, documentation and procedures.

Cost/Duration: $220K, 3 years

Prerequisites: Wave data must be available.

D08 CARGO/STRUCTURE INTERACTION

Objective: To determine the interaction forces between cargo, including wheeled vehicles, and ship structure due to rigid-body and elastic-body ship motions.

Method: Acceleration histories will be secured from available sources and studied to obtain characteristic profiles of amplitudes and frequencies. These will be converted into reactive forces.

Cost/Duration: $60K, 1 year

Prerequisites: Adequate shipboard-acceleration data bases.

D09 IMPACT ON STRUCTURAL ELEMENTS, ANALYSIS AND CRITERIA

Objective: To provide procedures to analyze the time-stress-deflection history of plate panels, beams and major structural components subject to pulse-type loads, and to provide limit-load criteria.

Method: An analytical study to develop computerized design methodology which will determine dynamic stresses in local structural elements. The procedure to include dynamic load factors and plastic response.

Cost/Duration: $100K, 1½ years

D10 PREDICTING WAVE-IMPACT LOADS

Objective: To provide an analytical method to predict the magnitude, time history and three-dimensional spatial descriptions of wave-induced loads.

Method: Develop mathematical models that can utilize model or full-scale data on wave shapes, ship motions and closing speeds to develop local pressures and hull girder responses. Study to cover bottom slamming, bow flare impact, appendage impact, green water loads and stern/aft slamming.

Cost/Duration: $150K, 2 years

D11 PREDICTING PROPELLER-INDUCED FORCES

Objective: To provide techniques by which it will be possible to predict forces on hull and appendages induced by the propeller.

(a): Predicting the Wake of the Propeller

Method: Develop an analytical procedure to predict the water velocity distribution at the propeller with consideration of hull form and ship speed.

(b): Deriving Time-Phased Forces

Method: Develop an analytical procedure for predicting the time history of propeller-induced forces as a function of wake, propeller configuration and rotational rate.

Cost/Duration: $500K, 3 years

D12 VIBRATIONS PREDICTION MODELING-TECHNIQUES IMPROVEMENT

Objective: To improve the prediction of vibrations through the development of improved modeling techniques.

Method: Study possible improvements to modeling techniques that can provide an acceptable level of amplitude and frequency prediction while minimizing the cost.

Cost/Duration: $60K, 1 year

D13 DESIGNING FOR CORROSION

Objective: To provide design methods that will allow effectively for corrosion of the structure.

Method: Assess the impact of local and overall corrosion, including stress build-up in way of local pitting, on the life of the hull. Consider the effect of replacement of badly corroded components. Develop criteria for hull design and component replacement.

Cost/Duration: $350K, 2 years

D14 DESIGNING ARCTIC SUBMARINE STRUCTURE, METHODS AND CRITERIA

Objective: To provide design methods and criteria for the design of the structure of arctic submarines.

Method: Define design concepts that will lead to structures suitable for the operating environment. Aim especially at the early-phase feasibility studies that will demonstrate the viability of the concept.

Cost/Duration: $75K, 1 year

D15 VIABILITY OF CONCRETE HULLS

Objective: To determine the types of hulls or platforms for which reinforced concrete is a viable alternative to steel.

Method: Assess material concepts, construction techniques, operational characteristics, economics and safety of reinforced concrete ships and platforms. Determine the types of hulls or platforms for which concrete is a viable alternative to steel.

Cost/Duration: $150K, 1½ years

D16 DESIGNING CONCRETE STRUCTURE, METHODS AND CRITERIA

Objective: To provide procedures and guidelines for designing concrete structures.

(a): Design Methods and Criteria

Method: Consider overall hull bending, local loading and structural deflection, including the application of probabilistic and limit load criteria. Develop design procedures and criteria.

(b): Designing for Dynamic Loading

Method: Develop techniques to analyze the response of reinforced concrete structures to impact loads including slamming and collision. Develop empirical criteria for energy-absorption characteristics.

Cost/Duration: $550K, 3 years

Prerequisite: The scope of this work parcel should be limited to those concrete structures revealed to be viable competitors by work parcel D15.

D17 TRANSVERSE-STRENGTH ANALYSIS

Objective: To provide a technique for transverse-strength analysis.

Method: Use existing analytical procedures to relate hull principle dimensions to prescribed levels of transverse seaway loads. Use simplified analytical procedures to determine the response of the transverse framing in a manner similar to that now used for longitudinal bending.

Cost/Duration: $180K, 3 years

AD-A140 275 SHIP STRUCTURE COMMITTEE LONG-RANGE RESEARCH PLAN - GUIDELINES FOR PROGRAM DEVELOPMENT(U) SHIP STRUCTURE COMMITTEE WASHINGTON DC E M MACCUTCHEON ET AL. 1982

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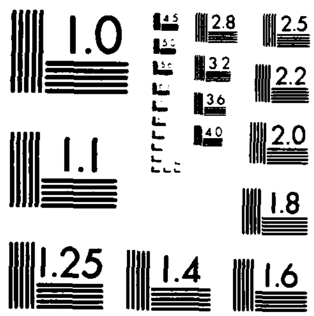

D18 SUPERIMPOSING DESIGN LOADS

Objective: To provide a relatively simple method of assessing the net reaction of the hull structure to various combinations of loading of various frequencies.

Method: Assess interrelationships and non-linearity effects of various load conditions including still water, low frequency, high frequency and other loadings. Assign relative importance to resulting stress and deflection reactions. Develop a procedure for superimposing the loadings.

Cost/Duration: $80K, 1½ years

D19 RATIONAL SHIP DESIGN

Objective: To provide a rational methodology for ship structural design and a technique for coordinating and monitoring design input from all goal areas.

Method: Develop a master flow chart for ship design information, including inputs from ship owners, ship operators, shipbuilders, government agencies, regulatory bodies as well as research and development plan and a program management plan.

Cost/Duration: $75K, 1 year, with periodic updates

D20 DESIGNING AGAINST FATIGUE

Objective: To improve the procedures and criteria for designing to reduce failure by fatigue:

(a): Loading Criteria

Method: Establish stress histories for various types of ships and ocean areas. Analyze wave loading, high-frequency loads, dynamic loads, thermal loads, etc. and employ probabilistic methods to profile the histories.

(b): Uncertainty/Reliability

Method: Characterize the variability of fatigue failure probability by analyzing the variability of causal factors such as materials fatigue resistance, stress estimates, cycle counting, corrosion or fabrication quality.

(c): Random Loading

Method: Develop damage criteria for design by evaluating alternative criteria such as the Palmer-Miner which provides for variable-stress histories.

Cost/Duration: $550K, 4 years

Prerequisites: This work parcel depends on the availability of adequate operational records and structural fatigue test data.

D21 COLLISIONS AND GROUNDINGS

Objective: To provide structural design methods and guidelines which will increase the collision and grounding resistance and the residual strength after damage of ships.

(a): Collision and Grounding Data Base

Method: Accumulate and analyze casualty reports from existing reporting systems to determine potential improvements and superior techniques of structural design.

(b): Improved Design Techniques for Structural Resistance to Collision and Grounding

Method: Develop methods for the rational prediction of energy absorption and guidelines for more resistant structures.

(c): Residual Strength and Restored Strength

Method: Develop techniques to assess residual strength after collision or grounding and after repair.

Cost/Duration: $235K, 4 years, plus a continuous data gathering activity.

D22 HULL GIRDER DEFLECTION CRITERIA

Objective: To provide design guidance on allowable deflections for the hull girders of various ship types.

Method: Analyse the response of typical shafting and piping systems to various levels of curvature of the hull. Establish a rationale for proposed limits of deflection and guidance to designers on the impacts of large deflections.

The project is intended to eliminate arbitrary limits on hull-girder deflection and ease the introduction of higher strength steel or lower elastic-modulus materials.

Cost/Duration: $150K, 2 years

D23 ICE LOADING CRITERIA

Objective: To better define sea-ice loading on the hull as a basis for refining the ice strengthening requirements.

Method: Canvass industry for data on the incidence and type of ice encountered. This would include pack ice, brash ice and ice on deck, rigging or cargo. Employ statistical methods to compute consequent ice loads to serve as a basis for formulating criteria.

Cost/Duration: $50K, 1 year

D24 OPTIMIZATION AMONG DESIGN CRITERIA

Objective: To provide techniques to perform structural design in optimum satisfaction of the three major structural design criteria; weight, cost (initial and operating) and risk of failure.

Method: Develop an analytical means to satisfy simultaneously more than one structural performance criteria. There should be recognition of the effects of quality control and lifetime surveillance.

Cost/Duration: $40K, 1 year

D25 DESIGNING FOR INSPECTABILITY AND MAINTAINABILITY

Objective: To provide guidelines for access to ship structure to facilitate inspection and maintenance.

Method: Structural engineers, inspectors and draftsmen establish adequate sizes and geometry for access holes, catwalks, ladders, void spaces, double bottoms and permanent scaffolding to provide for satisfactory inspection and maintenance. Included would be consideration of cargoes requiring special attention. These data would then be assembled into guidelines.

Cost/Duration: $50K, 1 year

D26 DESIGNING TO MINIMIZE GREEN WATER LOADS

Objective: To provide ship designs that will minimize the amount and effect of green water on the deck.

Method: Develop and validate a computer program that will optimize freeboard and shear for selected degrees of reserve buoyancy. Modern

concepts for handling hull configurations and motions would be invoked along with statistical representation.

Cost/Duration: \$135K, 3 years

D27 VIBRATION STUDIES SCHEDULING IN THE DESIGN CYCLE

Objective: To determine design cycle milestones for the completion of vibration studies having degrees of complexity consistent with the stage of maturity of the design.

(a): Time Phasing of Vibration Studies

Method: Study the timing of the needs for vibration information in the ship design cycle. Consider the availability of required vibrational input data for the needed studies. Note the shortfalls of data availability and seek remedies.

(b): Matching Accuracy to Maturity of Design

Method: Reconcile and compromise the needs for and availability of vibrational data during the design cycle. Schedule the availability of vibrations analyses to suit the need.

Cost/Duration: \$75K, 3/4 year

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COMMITTEE ON MARINE STRUCTURES
Marine Board
National Academy of Sciences - National Research Council

The Committee on Marine Structures (Formerly Ship Research Comittee) has technical cognizance of the interagency Ship Structure Committee's research program. For this project, SR-1296, they prepared the project prospectus provided the technical guidance, and reviewed the project report with the investigators.

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